ELEMENTS
OF
SOMATOLOGY.

MACLEAN.

To

Mr J. Abel,

From his sincere frien[d]

John MacLean J[r]

Dec 25th 1859.

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OF

SOMATOLOGY:

A TREATISE ON THE

GENERAL PROPERTIES OF MATTER.

BY

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PREFACE.

Some years ago, being very much confined by ill health during the winter, I occupied much of my time in studying and writing upon the subject of the following treatise, taking the matter from whatever quarter it was presented, solely for my own improvement and amusement, without any thought of ever publishing it. Having found many pupils slow in understanding the difference between the physical and chemical properties, I have subsequently read portions of it at the beginning of my courses of lectures on chemistry, as I think not without benefit to my classes. When afterwards the thought of publishing presented itself, private considerations prevented. More recently, the whole of it has been rewritten; and a full index framed, and it is now sent forth in search of readers. Should success attend this effort, and other engagements permit, it may be followed by treatises on other, but kindred, branches of sciences now in the course of preparation.

G. M. M.

Alleghany City, Pa., Oct. 18th, 1858.

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ELEMENTS OF SOMATOLOGY.

INTRODUCTION.

1. As in the Greek language the same word κοσμος signifies the world, or universe and order, and in the Latin language *mundus* has both meanings; so, in English, the word *nature* always brings to the mind, with greater or less distinctness, the idea of beauty, order, or adaptedness of things to their condition. The same is probably true of the corresponding words in every language.

Nature may be defined the system of the world or the universe; and may be considered as embracing two great departments, mind and matter. Mind is the part of a being which perceives, thinks, wills, and is susceptible of moral emotion. Matter or substance is what may be seen or felt, or may affect any of our senses. Of the absolute nature of either mind or matter we can have no definite idea; we know them only by their properties: these are so different as to lead, perhaps universally, to the division of general sciences into two great classes corresponding to the two objects of contemplation, viz. Metaphysics, the science of mind, and Natural Philosophy, the science of matter. These, though to a certain extent independent, are, nevertheless, in some respects closely allied.

The earliest exercise of the powers of observation and

reason must have led man to recognise resemblances and differences among the various objects in nature; and becoming aware that by carefully investigating the properties of a few he may obtain a general knowledge of all, sufficient to secure the possession of what is desirable, and the avoidance of what may be hurtful, he must soon have been led to arrange the objects referred to into the three great kingdoms of nature—the animal, the vegetable, and the mineral; and this slight attainment must have produced a thirst for more knowledge, and led to the invention of various methods by which to obtain this object. The classification and minute description of these objects constitute Natural History. When examining the forms and qualities of bodies, the mind takes cognizance of motions or changes: simple expressions describing them are called General Truths or Laws of Nature; and their assemblage is named Science of Philosophy, in contradistinction from Natural History—the term science here meaning exact knowledge. All motions, changes, or phenomena (using these terms as synonymous) of the universe are repetitions or mixtures of a few simple motions, which science assumes as its basis to be in all cases as constant and regular as in producing the return of the seasons. Natural History, Science of Philosophy, and Metaphysics embrace the whole sum of the knowledge of nature. The properties and relations of all material nature fall within the domain of Physical Science or Natural Philosophy in the most extended sense of the term; but they are divided into organic and inorganic; and the inorganic are subdivided into terrestrial and celestial. The study of the heavenly bodies, together with certain terrestrial phenomena, intimately connected with their influence, constitutes a distinct science—Astronomy. The remaining departments of Physical Science are, Physique or Natural Philosophy proper, Chemistry, and Science of Life.

2. Natural Philosophy, in this restricted sense, views

matter in masses, explains the phenomena of the material world by the properties of matter, and treats of the agents which produce the changes in inorganic matter; such as the unknown causes of attraction, light, heat, electricity, etc. Its laws govern every phenomenon of nature in which sensible change of place occurs, being concerned alone in the greater part, and regulating the remainder originating from chemical action or from the action of life. Chemistry investigates the peculiar properties of individual bodies, their reactions, the laws of their combinations, decompositions, etc. Iron, sulphur, carbon, and about sixty other bodies, singly obey the laws of physics. Two or more in contact, under certain circumstances, exhibit new orders of phenomena. Iron and sulphur heated together form a yellow mass unlike either; under other circumstances they separate. They are not withdrawn from physical laws: the phenomena are merely modifications of general attraction and repulsion. Many chemical are only the beginnings of purely mechanical changes, *e.g.* in the explosion of gunpowder the new chemical arrangements of the particles causes a change of form and motion. All chemical manipulations are directed by physics alone. Chemistry is but a superstructure upon physics.

In vast multitudes of bodies matter exists in its most complicated state, under the influence of life, being arranged into organs capable of performing certain functions essential to the continuance of life, or otherwise useful to the being. Such collections of matter are called "organized bodies." They are arranged in two classes, viz. vegetable, which are fixed to the soil; and animal, which have the power of locomotion. The science of life investigates growth, sensation, self-motion, decay, death, &c. It is divided into animal and vegetable physiology. The phenomena of which it treats occurring in structures obedient to the laws of chemistry and physics, it is truly a superstructure upon

those sciences, and cannot be studied independently of them. The greater part of the phenomena of organic life are merely chemical and physical phenomena modified by an additional principle. Terms of quantity are required to express most of the facts and laws of physics, chemistry, and life; *e.g.* the magnitude of a body, the force of attraction between bodies and its relation to their distances: hence the necessity of standards. The rules for applying these standards and comparing quantities constitute the Science of Quantity, or Mathematics.

3. In all investigations of the course of nature, two distinct steps are taken, the first of which is observation, which may regard only the phenomena as presented to us by nature in its ordinary course or in extraordinary and disturbed conditions, which conditions may be the result of our own intention, and is then called experiment. The second step is a metaphysical one, and may be either of two very different kinds, corresponding to the *a priori* and the *a posteriori* or inductive methods of reasoning upon mental subjects. The former alone would very slightly extend our knowledge; even experiment, unless aided by reasoning, which is the second step, would be of little avail. The mere observer of nature will perceive differences between a stone, a tree, and a horse; but if he do not reason upon the differences, his knowledge will be but an assemblage of truths of little or no practical use. The chemist may observe that bodies have various forms or colors; he may find them to change their form or color; but if he do not reason upon these data, he will have little knowledge of the nature of these bodies, of that of light, or of the causes inducing the changes: and however many facts he may thus accumulate, his knowledge will never deserve the name of science; but will be absolutely useless, even as the most precious treasures buried in the sands of a vast desert. Of the two strictly mental steps in investigation already

referred to, the *a priori* is that in which the mind draws particular conclusions from general principles which have been assumed, or infers particular effects from known causes of a more or less general kind. With regard to the other step, the *a posteriori* or inductive, there has been in many minds much misapprehension, arising from the term induction being used in different senses; sometimes as referring only to the collection of data, and at other times as denoting the process of reasoning from those data.

Thus induction has been thought to differ from syllogistic reasoning, but incorrectly; for though in the process of induction the thoughts may not be presented in the form of syllogisms; there is no correct induction which is incapable of being expressed syllogistically. The *a posteriori* or, inductive process may therefore be called the syllogistic: by it we draw general conclusions from particular facts, we decide upon general causes from the knowledge of several particular effects: the accuracy of such conclusions will depend very much upon the number, variety, and nature of the particulars. Having by induction obtained these general conclusions the mind may, using them as premises, deduce particular consequences. This deduction is but a form of *a priori* reasoning, and may be used in confirmation of inductions. Having attained to certain conclusions by reasoning upon one series of phenomena, we sometimes infer similar conclusions, without distinct argumentation, as to another series of phenomena, some resemblance being supposed to exist between the two series: we are then said to reason from analogy. The accuracy of all such conclusions will, of course, depend upon the degree of resemblance or agreement existing between the classes of phenomena. By many minds the meanings of the terms law, cause and effect (terms which are frequently used) appear to be greatly misapprehended: by law is not meant an arbitrary decison controling the properties of matter which might as

well in the nature of things be the contrary of what they are, but an extended generalization expressing the ordinary course of occurrences in nature. The terms cause and effect refer to steps in that course, and are to be used somewhat in the sense of antecedent and consequent: for two events, of which one appears to be the inevitable result of the other and entirely dependent upon it, may both be but consecutive results of quite another antecedent. In physical matters we are not to look for the absolute certainty found in mathematics; in them we can only say that particular effects having been constantly produced under certain circumstances, they probably depend on those circumstances, and they will most likely be produced as long as the circumstances continue. Such is the correct meaning of the expression, "laws of nature."

The celestial and all great terrestrial phenomena are said to be governed, and the healing art, engineering, etc., to be influenced by the laws of physics; which means that the former are entirely, and the latter to some extent, in accordance with the generalizations expressed by the so-called physical laws. The phenomena may be simple; we are then said to assign its cause, when we adduce the generalization or law of nature to which it appertains: or it may be complex, in which case its explanation requires separation into its several parts, and the reference of each to its appropriate generalization. Pure mathematics is not an inductive science, but strictly deductive, and admits no method of proof but by deduction.

4. The terms hypothesis and theory are often used, sometimes very indefinitely, as expressive of the reliance to be placed upon statements of the laws of nature, or of the connexion existing between effects and their supposed causes. It may not be out of place here to endeavor to assign some definite idea to these terms. The mind having by observation, induction, deduction, or anoalgical reasoning, acquired

the knowledge of a number of phenomena, and attained to generalizations expressive of them, may conjecture something to have been the originating cause of the whole series of facts; this conjecture is an hypothesis. It affords us an example, but by no means necessarily accurate, of *a priori* reasoning. It has been remarked by Darwin, that to think is to theorize. A theory may be defined an expression of mental apprehension of probable generalization. A theory, if pure, is the result of induction; but the whole expression may be in part hypothetical; it must in either case depend upon the observation of phenomena. In the days of Lavoisier, all acids whose compositions were known contained oxygen; hence he induced the generalization, or formed the theory, that oxygen is the universal acidifying principle. The observation that all bodies under favorable circumstances approach each other, has led to the hypothesis that all matter is possessed of a power or property called "attraction." A large number of facts are called electrical; a fluid has been conjectured to exist, possessed of properties which will readily account for the various phenomena; the explanation of these phenomena on this supposition is called the electrical theory; it is a hypothetical theory.

The following extract is from Cavallo:—

"The axioms of philosophy, which have been deduced from common and constant experience, are so evident and so generally known, that it will be sufficient to mention a few of them only.

"I. Nothing has no property; hence

"II. No substance, or nothing, can be produced from nothing by any created being.

"III. Matter cannot naturally be annihilated or reduced to nothing; and although many things appear to be utterly destroyed, as suppose by the action of fire, by evaporation, &c., yet in those cases the substances are not annihi-

lated, but they are only dispersed or divided into particles so minute as to elude our senses.

"IV. Every effect has, or is produced by, a cause, and is proportionate to it.

"The rules of reasoning in philosophy, which have been formed after mature consideration, and which must serve to prevent errors as much as possible, and lead us along the shortest and safest way to the attainment of true and useful knowledge, are as follows :—

"I. We are to admit no more causes of natural things, than such as are both true and sufficient to explain the appearances.

"II. Therefore, to the same natural effects we must, as far as possible, assign the same causes.

"III. Such qualities of bodies as are not capable of increase or decrease, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

"IV. In experimental philosophy, we are to look upon propositions collected by general induction from phenomena, as accurately or very nearly true, notwithstanding any contrary hypothesis that may be imagined, till such time as other phenomena occur, by which they either may be corrected, or may be shown to be liable to exception."

SOMATOLOGY.

5. This name, derived from the Greek words σωμα, body, and λογος, discourse, is defined, the doctrine of bodies or material substances, and is applied to that department of natural philosophy which treats of the nature and constitution

or general properties of bodies in contradistinction to the peculiar properties of individual bodies, or classes of bodies. The visible universe is made up of minute atoms called matter; which term conveys no idea of figure. A separate and determined portion of matter is called a body. The minuteness of the parts into which bodies may be divided, has led to the question whether matter really exist. In reply, it is usual to refer to weight, the proofs of indestructibility, and the occupancy of space, called impenetrability. Of the intimate nature of matter, as has been already intimated, we know absolutely nothing, being acquainted only with its properties. The present state of knowledge does not enable us to determine whether there be but one kind of matter consisting of particles of definite shape, size, density, hardness, &c., which by various modifications forms all bodies in the universe; nor, there being more than one kind of matter, to form the slightest conjecture of their number. It is usual, however, to attribute the difference in the properties of the various bodies to differences in the nature of the atoms of which they are formed, and to consider the bodies as constituted by the aggregation of molecules which are assemblages of atoms, the atoms not being in absolute contact, but separated by an atmosphere of caloric. General properties of matter are properties belonging to all known bodies. The following fourteen are now recognised as general properties of bodies:—1. Extension. 2. Impenetrability. 3. Figure. 4. Divisibility. 5. Indestructibility. 6. Porosity. 7. Compressibility. 8. Dilatability. 9. Mobility. 10. Inertia. 11. Attraction. 12. Repulsion. 13. Polarity. 14. Elasticity.

We can form no conception of matter in the absence of extension and impenetrability.

EXTENSION.

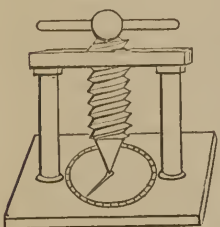
6. Extension is the occupation of a portion of space by a body. It is observed in three directions, viz.—of length, breadth, and thickness. Magnitude, size, bulk and volume are other names for extension. Space is without; and may be in the mind indefinitely divided. The idea of space is not received by experience, but exists in the mind, independently of, but in its exercise constantly united with, experience, of which it is the beginning, as all the idea we can entertain of external bodies must be in connexion with that of the existence of space. In like manner it is perhaps impossible that the idea of space should arise in the mind independently of that of matter; but having conceived the idea of two distinct portions of matter, that of the distance between them will readily follow, and it may be entirely distinct from that of any matter occupying that distance; we may also conceive of either or both these portions of matter being annihilated or removed, without the portions of space being occupied by any other bodies; in both cases we have the single idea of space. The portion of space from which matter is supposed to be or has actually been removed, is called "pure space," "void space," or "vacuum;" examples of it are found in vessels from which all air has been entirely removed by an air-pump, they being destitute of ponderable matter; and, although they can be crossed by light, heat, and other imponderables, unless these be material, are destitute of all matter.

It is often desirable to ascertain the magnitude of a body; this is accomplished by comparing it with some other whose dimensions are assumed as a standard. The selection of a standard is arbitrary: in English measures the size of a full grown grain of barley, being considered as always the same, is taken as the standard; hence the measure barley-corn. But

the measure cannot be viewed as invariably fixed in this case, nor in any other in which the standard is not necessarily undeviating in size. The only system of measures possessing this unvarying uniformity, is the French system, or such as has had its accuracy determined by comparison with it. This French system is founded on the length of a meridian of the earth, as ascertained by a series of carefully conducted measurements: a forty millionth of the length of the meridian is taken as the length of a metre assumed as the unit of measurement. This French system, being referred to in most scientific works of modern times, should be well known in comparison with other systems.

An index revolving parallel to the circumference of a screw bearing a certain relation to the spaces between the threads of the screw, an arc of the circle traversed by the index may be considered an accurate measure of the space through which the point of the screw passes. (Fig. 1.) If the threads of the screw be one half, one quarter, or one eighth of an inch apart and the circle be divided into one hundred equal parts, then on turning the screw the point of the index would pass over one part, while the screw passes one two hundredth, one four hundredth, or one eight hundredth part of an inch. Or the intervals between the threads of the screw being much smaller, or Hunter's Compound Screw (Fig. 2—*see note, page* 20) being employed and the circle being divided into a larger number of parts, the minutest space may be measured, especially with the aid of a microscope.

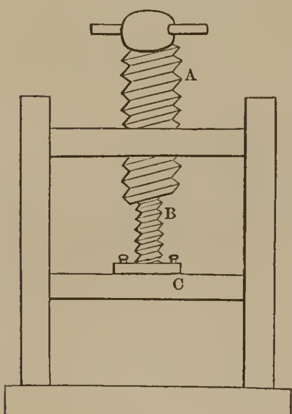
Fig. 1.



IMPENETRABILITY.

7. Impenetrability is that property of matter by which a body excludes every other body from the part of space itself occupies. As by muscular effort we acquire the idea of extension, by it we also obtain that of resistance, which proves the impenetrability of the opposing body. This impenetrability is less perceptible in liquids than in solids, not because of its being possessed in any less degree by the former than by the latter, but because the particles of fluids have the property of mobility to such an extent as to require a very slight force to cause them to move upon each other; whereas in solids the particles are retained in contact

Fig. 2.

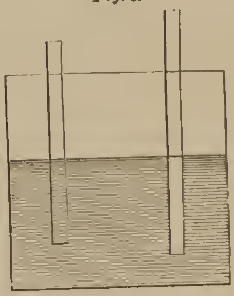


Note. In this contrivance, while the working point is driven forward by one screw with a large thread, it is drawn back by another with a less thread, and consequently advances only in proportion to the difference of size of the two threads. A being a greater thread playing in a fixed nut, B a less thread upon a smaller cylinder playing in a hollow screw within the large cylinder, and C a board moved by them. During every revolution of the screw A descends and B ascends through spaces equal to the distances between their respective threads. If A have twenty threads and B twenty-one in an inch, during one revolution A will descend through the twentieth, and B ascend through the twenty-first of an inch, and consequently B will descend through the difference of the distance, that is, through the two hundred and fiftieth of an inch.

with each other with such energy as to demand considerable force to detach them; and if fluids be so confined as to interfere with their freedom of motion, they clearly manifest their impenetrability. A drop of water ceases to prevent the actual contact of our hands, only by being pushed out of their way; otherwise, action and reaction being equal, it must cease to be matter. This existence of an insuperable force of resistance is not self-evident as supposed by some, nor is it the result of invariable experience as has been otherwise taught; it can never be the result of observation which cannot attain that length; but it is a corollary to the axiom that action and reaction are equal. But for this property, the matter of the universe might be concentrated to a point of space.

The following examples illustrate the impenetrability of matter. One solid ball, as of ivory, cannot be pressed into the substance of another, and then a second, etc., into it; so, a mass of gold cannot be driven into one of silver. Air, escaping from a vessel under water, ascends through the liquid only by displacing its own bulk of water. Millions of pounds cannot push down the piston of a forcing pump or of a hydraulic press unless the water below it can escape. If one end of a glass tube, open at both ends, be immersed

Fig. 3.



in water, it will be immediately filled to the level of the surrounding water (Fig. 3); but if while the bottom is left open, the top be closed by the thumb, the resistance of the contained air will prevent the entrance of the water. In like manner, the resistance of the con-

fined air prevents water entering a diving-bell, or a jar immersed with its mouth downwards. Weights laid upon bladders filled with air, or on the piston handle of a closed air-pump, are kept in position by the repelling force of the air. It is true that some cases of mixture would appear to disprove the impenetrability of matter, *e. g.* water and alcohol when mixed have less bulk than before; but this only proves that one of the fluids fills vacuities in the other; and possibly, as has been conjectured, some finer fluid may have escaped on mixing the two. A nail driven into a mass of wood does not penetrate the individual atoms, but is insinuated into the interstices previously existing or formed by the forced movement of the atoms.

FIGURE.

8. Figure has been defined the boundary of extension. Resistance being offered by a body to the entrance of the hand into its space, the obstruction is found to have limitations in directions relative to each other; from these limitations we acquire the idea of figure. Inorganic matters frequently assume regular geometrical forms, which are called crystals; though various matters may assume very nearly the same form, there being but slight differences in the measurements of the angles, in general each species on crystallizing assumes a peculiar form, though the same species may assume either of two or three forms, when it is called dimorphous or trimorphous; the mass may be destitute of symmetry, it is then called amorphous. In liquids or gases the particles move too freely to assume a definite shape; these classes of bodies, therefore, take the form of the vessels containing them. Shadows and images, produced by various optical means, show that figure is not proof of material existence.

DIVISIBILITY.

9. Divisibility is the capability of being separated into parts. All bodies are capable of being subdivided till the parts become invisible by the naked eye; by a microscope they will then be found susceptible of much further subdivision; after which, in some instances, they may be dissolved, and thus again subdivided to an extent preventing detection by any optical means. One pound of wool has been spun into yarn 100 miles long. Gold, by being hammered, is reduced to leaves so thin, that 360,000 must be laid together to produce the thickness of an inch; if made into a book, 1800 such leaves occupy only the thickness of an ordinary leaf of paper. Hence a volume of gold an inch thick would contain as many leaves as a library of 1800 volumes with 400 pages each. On gilded silver wire, two ounces of gold are extended over 1,351,900 feet, rather more than 768 miles. Platinum has been drawn into wire finer than human hair. Every instance of solution affords an illustration of the divisibility of matter, and the more marked as the solution is diluted, *e. g.* at 212° F. one grain of lime requires for its solution 1270 grains of water, each grain of the liquid of course holds $\frac{1}{1270}$ of a grain of lime; now this solution may be indefinitely diluted, and the minute quantity of lime is further divided by every successive addition of water. Iodine requires for its solution 7000 parts of water, and to that quantity it imparts a brown color, which is still perceptible after considerable dilution. One part of ammoniacal hyposulphite of silver gives an intense sweetness to 32,000 parts of water. Carmine and sulphate of copper are both compound substances, and one grain of either will tinge every drop of a gallon of water; every grain of the water will then hold in solution $\frac{1}{61440}$ part of a grain of the solid, and

may be diffused through another gallon, or any larger quantity of water, and be proportionally divided. Starch and then a little chlorine being added to one part of iodide of potassium dissolved in 480,000 of water will cause the whole to assume a decided blue color. The thickness of a soap bubble just about to burst is but $\frac{1}{4000000}$ of an inch.

10. Organized nature presents innumerable examples of extreme division of matter. The diameter of the thread of the silkworm is but $\frac{1}{2000}$ of an inch. Two drachms of a spider's web drawn out in a single thread would extend 400 miles. The microscope detects in the milt of the cod-fish, or in water in which certain vegetables have been infused, animalcules of which many thousands together do not equal in bulk one grain of sand; each of these have their blood and distinct organs; many of them have indeed organs as complex as those of the elephant or whale. The body of an animalcule is composed of the same ultimate atoms as that of man. From observations on this class of beings it has been calculated that a single pound of matter contains more living creatures than there are human beings on the globe. Illimitable divisibility is also evinced by odorous matter. By the sense of smell the presence of many matters may be detected in the atmosphere of which not the slightest indication can be given by any chemical test. Dogs, it is well known, hunt by scent. The carrion crow has been thought to smell its food even at the distance of twenty miles: but some recent observations render it probable that these birds discover their food by sight and not by smell. A single grain of musk will fill a large room with its odor for twenty years, and be found to have lost but little weight.

The most wonderful efforts of man and the minutest objects in nature do not approach infinity: it is therefore impossible to say that matter is or is not capable of infinite

division; yet it is convenient to, and men of science generally do, consider the divisibility of matter as having a limit in what they call the ultimate atoms, which are supposed to be indestructible and incapable of change in themselves, though susceptible of impression from other atoms, and by union forming masses.

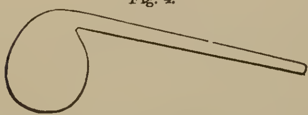
INDESTRUCTIBILITY.

11. Although matter be in various ways divided to such an extent as to elude detection by instruments or chemical tests, not an atom is destroyed. Water by boiling is converted into invisible steam, which is again condensed into the same quantity of water. Gold may be divided to the extent already mentioned by mechanical means; it may be dissolved by a liquid or dissipated by heat; and all be again recovered in the same solid form without the loss of a single atom. All the elements in the world can be thus separated a thousand times without being destroyed. Although it is impossible for man to form again the organized products of the animal or vegetable kingdom which have been once decomposed, yet he can present all their elements either in a separate state or in those of different combinations, and show that there has not been the slightest loss of material. When animals die, their particles pass into new forms of matter, reappearing as part of other animals or of vegetables.

This idea (that of the indestructibility of matter) has been entertained from the period of earliest history: it has been expressed in the following language: "the substance of which a body consists is incapable of being diminished in quantity, whatever apparent changes it may undergo. Its form, its distribution, its qualities may vary, but the sub-

stance itself is identically the same under all these variations:" it is also expressed in the reply of the philosopher, who being asked "what is the weight of smoke?" answered, "subtract the weight of the ashes from the weight of the wood which is burnt, and you have that of the smoke." This idea is the basis of all chemical reasonings and researches.

Fig. 4.

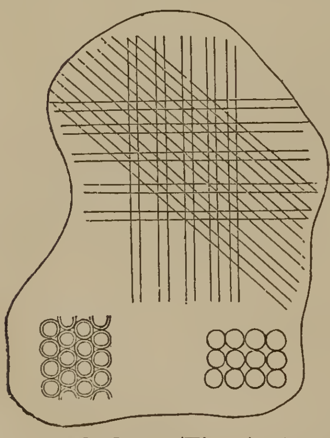


The chemist subjecting to the action of heat any matter in a retort or similar vessel does not imagine that he is creating or annihilating anything, but only that he is modifying the form.

POROSITY.

12. The particles composing even the most solid bodies are not in absolute contact at all points: the intervening spaces are called pores. This would be a necessary result, whether the particles of which the body was constituted were spherical, needle-shaped, or tabular. In many bodies these pores produced by the crossings of the constituent needles or plates, or by the partial contact of the spheres, is apparent to the naked eye (Fig. 5); in others can be discovered by the microscope, and may be detected by some means in

Fig. 5.



all, with the exception of glass, which appears to be totally impervious to all fluids. In common speech the term pore is restricted to interstices sufficiently large readily to admit gases and liquids. Crystallized sugar, sponge, and some stones, receive water into their pores without experiencing any change of bulk. A piece of wood, of chalk, or of sugar, being pressed to the bottom of a vessel of water, this fluid will enter its pores and expel the air contained in them. Clay, having been heated to redness, acquires the property of contracting its dimensions upon the application of heat, owing, doubtless, to the diminution of its porosity. Water while freezing increases in bulk; very strong vessels have been burst, and trees and rocks split by the consolidation of water contained within them. Its effects have been said to surpass those of exploding gunpowder; it contributes to the breaking down of mountain summits. That metals are porous is proved by the formation of alloys, their specific gravities being usually different from the mean of those of their constituent metals; by the celebrated experiment of the Florentine philosophers, who forced water through the pores of a golden globe, and by the translucency of gold leaf. Hydrophane affords an example of porosity in minerals; it is opaque, but being immersed in water it takes into its pores a quantity of the liquid and becomes translucent.

This property is not peculiar to solids, but is possessed also by liquids and gases. If equal bulks of water and concentrated sulphuric acid be mixed, the volume of the mixture will be less than the sum of their separate bulks. A contraction of volume also attends the mixing of alcohol with water; at 59° Fahr. dilute alcohol, with the specific gravity 0.927, contains in 100 volumes 53.94 of anhydrous alcohol and 49.84 of water, which have consequently contracted 3.78 volumes. Water when converted into steam under ordinary circumstances has its bulk increased 1694

times. If two gases which do not react chemically upon mere contact be introduced into the same vessel, however different may be their specific gravities, and whichever may at first occupy the lower position, they will after a time be found equally diffused. Vapor diffuses itself through the air. If a quantity of ether be introduced into two vessels half-filled, one with air and the other with hydrogen gas, the vapor of the ether will immediately rise and expand both airs, and ultimately to the same degree, but the hydrogen in half the time. Airs which are separated by glass with the minutest crack will commingle, the lighter gas passing usually with the greater velocity.

13. Animal and vegetable substances are remarkably porous. Leaves have numerous openings through their cuticles, communicating with cavities within their substance. These are too minute to be detected by the naked eye. They are most abundant in the lower part of the leaf; except in leaves as of the iris, both of whose surfaces are equally exposed to the light, and in those which float in the water, *e.g.* the water lily, in which they belong to the upper surface. When examined with a microscope, the petals of flowers are found abundantly supplied with these air pores. Pith is porous; in newly-formed parts, it being saturated with the ascending sap, is juicy. Bark and sap wood, being the parts through which the vegetable juices are circulated, are highly porous. This structure is very apparent in endogenous stems, in which the pith, wood, etc., are intermingled, *e.g.* Indian corn and rattan. It, however, is not confined to such, for the wood of exogenous stems is also highly porous. Wood sunk deep into the ocean has had its pores so filled as to become as heavy as stone. A large quantity of mercury being poured into a vessel with a wooden bottom, much of it will flow through the pores of the wood, and fall like rain. Wood has been preserved by putting it into an air-tight

vessel, removing as much as possible of the air, then forcing in a solution of silicate of soda or of silicate of potash, and finally immersing the wood into some acid or saline solution, by which the silicic acid is rendered insoluble. Wood has been saturated with solutions of salts, imbibed through the roots or base of the trunk shortly after being cut down. A poplar ninety-two feet high has, in six days, absorbed by the trunk sixty-six imperial gallons of a solution of pyrolignite of iron.

Blood is sometimes widely diffused in the cellular tissues under the skin, and in other parts of the body, evincing great porosity in those textures. Bone being a tissue of cells and partitions, must be porous. The cancellated structure is very apparent in the interior of bones. In young animals bones are colored by being fed upon particular articles. The shells of eggs are sufficiently porous to allow oxygen to be imbibed and carbonic acid to be exhaled during the process of incubation. If the passage of these gases be by any means prevented, that process is stopped. The nutritious part of the food of man is absorbed through pores in the coats of the smaller intestines, on the surface of which are villi, composed each of blood-vessels and absorbents, united by cellular tissue. In some parts these villi have been estimated at four thousand to the square inch. Albumen, casein, and fibrin are dissolved in the stomach; and they, as well as alcoholic drinks, pass directly through pores in that viscus. Water and carbonic acid pass from, and oxygen into, the blood, through the tranparent walls of the pulmonary cells in animals having lungs, and through the gills of fishes and amphibiæ. In human skins there are sudoriferous pores, whose average number is 2800, and in the palm of the hand 3528, to the square inch, through which the perspiration and carbonic acid pass off. The air changes the character of the blood, not only through the lungs and gills, but also through the

skin, in both air and water animals. A tendon or membrane which has become dry and hard will absorb water, and become soft and elastic. In some of the lower orders of animals life may be suspended a long time with impunity, and be restored by the application of water; thus the rotiform animalcules are restored to life and motion by the application of a drop of water. The lower extremities of a living frog were immersed for a short time into a solution of ferrocyanide of potassium, and the animal was then killed, and the salt was detected in the heart and lungs by the chloride of iron. The experiment was repeated with a frog which had been dead a few moments: the salt was detected equally in all parts of the body. In the former experiment it passed through the pores into the blood-vessels, and was carried to the centre of the circulation; in the latter it was imbibed through the pores throughout the system.

Density being the ratio of the quantity of matter to the magnitude of the body, the porosity must be inversely to the density.

COMPRESSIBILITY.

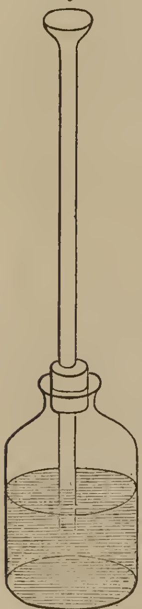
14. Compressibility is that property of matter which enables it to occupy less space upon the application of mechanical force. The particles of bodies being at a distance from each other, a sufficient force will compress them, *i.e.* cause them to occupy less space. Porous tissues are well known to be compressible; *e.g.* sponge may be reduced to one-tenth its bulk, and paper, wood and other tissues which have been penetrated by fluids, diminish under pressure and yield the fluids. Cork, in a strong glass vessel partly filled with water, will float; but if the vessel be forcibly filled with water, the cork will be compressed and sink: upon the removal of the pressure, the cork will expand and rise.

If a bottle be filled with fresh water, corked, and sunk into the sea to the depth of thirty or forty feet, upon drawing it up the water within will be found brackish; the cork must therefore be compressed so as to allow the waters to flow aside it; if it be sunk two hundred feet in the sea, the cork is rendered permanently heavier than water. Wood is compressible, as is shown, by the changes it undergoes when used as or confined by a wedge. A weight placed upon an upright pillar or rod, standing upon a sufficiently firm foundation, will shorten it. Stones under great weights are compressed; of this bases and columns sustaining edifices give evidence. Metals are hardened by percussion, becoming more compact and forming closer masses. Coins and medals receive their impressions under a powerful and suddenly-applied pressure, to which the metal yields as wax does to the fingers, not only changing its form, but receiving the most delicate marks, and occupying decidedly less space than before.

Liquids resist pressure, so that water was long thought to be absolutely incompressible. Water being forced through gold does not prove its incompressibility: indeed the experiment of the Florentine academician (§ 12) rather proves the contrary, for the water continued to drop for some time, although the pressure was not augmented. Several liquids in a glass tube, with a bulb blown at one end like a thermometer, have been found to expand when freed from the atmospheric pressure, and to contract when subjected to increased pressure. By such experiments, carefully conducted, it has been ascertained that, when the barometer stood at 29 and the thermometer at 50, spirit of wine suffered a compression equal to 0.000.066 of its bulk, olive oil 0.000.048, rain water 0.000.046, sea water 0.000.040, and mercury 0.000.003. The compressibility of liquids has been also proved in the following two ways: 1st. A hollow brass cylinder or cannon, furnished with a

stopper so adjusted as to indicate, upon the removal of the pressure, how far it had been forced, has been sunk in the sea to the depth of 500 fathoms. 2d. Into the neck of a bottle a capillary tube, furnished with a scale graduated into fractions of an inch, is firmly fixed, the capacity of the tube, as compared to that of the bottle, having been carefully determined; both are filled with the liquid to be experimented upon, and a bubble of air being entangled in the upper part of the tube, they are placed in a strong glass vessel, into the upper part of which is cemented a short iron cylinder, in which an air-tight piston is moved by a screw. The whole apparatus being filled with the fluid to be examined, the screw is turned, and the compression is indicated by the movement of the air bubble in the tube.

Fig. 6.



15. Gases are far more compressible than either solids or liquids. Carbonic acid, which was for a long time thought to be, in an uncombined state, a permanent gas, has, by great pressure, been reduced to a liquid. Air is compressible, as may be shown by luting a very long funnel-tube into a glass jar, so that no air can pass between the mouth of the jar and the funnel. (Fig. 6.) Upon pouring in water it will pass into the jar till the mouth of the funnel is surrounded, when no more will pass until it has filled the funnel so as to press with considerable force upon the water below, which will then act on the air and cause it to occupy less space. Or it may be more readily shown by immersing into water a vessel full of air with its mouth downwards; as the vessel descends the water will rise within it, the air being compressed by the column of water

above the level of the vessel's orifice, with the resistance of the water below. (Fig. 7.) If a piston be accurately fitted to a tube with a uniform bore having one end closed, by carefully pressing in the piston the air can be condensed, with very little force, into half its bulk; and, with greater force, into still less space. By the following experiment, it may be shown that the volume of the air is inversely as the compressing force. Take a long glass tube of uniform bore, closed at one end, and bend it at a part between that end and the middle, so that the parts between the bend and the extremities shall be parallel; place it with the bent part down (Fig. 8), and pour in sufficient mercury barely to confine the air in the closed part; this air is now under the same pressure as the circumambient air, which is indicated by the barometer; now pour in more mercury, and the confined air will be compressed, and the mercury will rise within the closed part of the tube. By measuring the altitude of the column of mercury in the open part above the level of that in the closed part, the relation of the volume of the air to the amount of pressure is readily ascertained. Thus, if that column be nine times as high as the mercury in the barometer, the confined air will be pressed upon by its weight in addition to that of the atmosphere—that is, by a weight equal to ten atmospheres—and will occupy one-tenth its original bulk. There appears to be no limit to the compressibility of gases, except the change

Fig. 7.

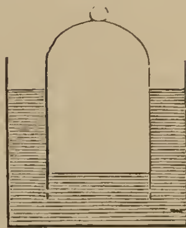
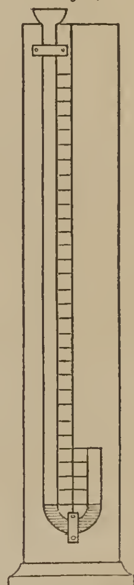


Fig. 8.



of form which some of them experience under great pressure.

DILATABILITY.

16. Dilatability is that property of matter which enables a body to increase its space. That bodies are dilated by simply removing pressure is shown with the air-pump: a bag of gum elastic, or other similar material, partially filled with air and securely tied, being placed under the receiver of an air-pump (Fig. 9), upon removing the air from the receiver, the bag will become distended to its utmost capacity. If a glass matrass, filled with water, and inverted into a cup filled with the same fluid, be similarly placed, upon removing the air from the receiver, bubbles of air will be seen rising through the water, increasing in size as they rise, and collecting in the upper part of the matrass (Fig. 10); after all the air is separated from the water, its bulk will enlarge and force down the water as the exhaustion proceeds. As air is pumped from the surface of water, its place is supplied by vapor. This may, in like manner, be removed and its place supplied, and so on till the whole has disappeared; if ether be used instead of water, the vaporization proceeds with rapid ebullition.

Fig. 9.

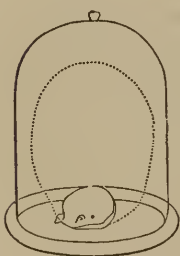
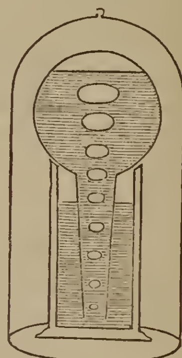


Fig. 10



Bodies are dilatable by mechanical force: thus when a

wire is drawn in the direction of its length, or when a dependent bar sustains a weight from its free extremity, its particles are supposed to be forced asunder, the increase of length being more than equivalent to the diminution of diameter. The density of india rubber is thought to be lessened when it is greatly and repeatedly stretched.

17. Heat dilates bodies. A small quantity of air being confined in a glass over a liquid, will be seen to enlarge with a slight increase of heat. A bladder not quite full of air will, upon being heated, become distended. Oils, alcohol, ether, water, mercury, and other liquors are expanded by increase of their temperature; but water differs from the others in having its bulk increased by diminishing its temperature below 40° F. A metallic rod, which will fill an opening in another metal, and occupy the space between two fixed points while cool, will, upon being heated, become too large to be received into the opening, or between the points. Rims of iron are, while hot, easily fitted to carriage wheels, which they would not embrace while cold; so also iron hoops by being heated are securely fastened on casks, etc. Whatever, therefore, is used for accurate mensuration, should be employed at a given temperature, or allowance should be made for the changes.

Many bodies by the application of heat have their particles so far removed as to change their form; thus solids become liquids, and liquids vapors. It is probable that all solids would undergo this change, if they could be protected from chemical reaction, and be at the same time freed from pressure. The temperatures at which these changes take place, though quite different for different bodies, are fixed for each kind: thus, mercury always melts at about —40° F., ice always at 32°, olive oil at 36°, tallow at 92°, sulphur at 226°, lead at 612°, and silver at 1873°. Under ordinary circumstances, most liquids pass slowly into vapor, at

higher temperatures they boil. The barometer standing at 30 inches, hydrochloric ether boils at 52°, sulphuric ether at 96°, alcohol of s. g. 0.798 at 173°, water at 212°, oil of turpentine at 314°, whale oil at 630°, and mercury at 662°. Two opinions have been entertained relative to the nature of heat, viz. 1. that it is an imponderable fluid entering into bodies becoming warm, and leaving cooling bodies: 2. that there is diffused through all space an ethereal fluid undulations of which cause the phenomena of heat, as undulations in the air cause those of sound. This dilatation of bodies by heat has been applied to the measuring of its quantity; thermometers and pyrometers are instruments used for that purpose. The great dilatability of air fits it for detecting slight changes of temperature, but renders it inconvenient for general use.

Alcohol having never been solidified, anwers well for measuring low temperatures; but being progressively more expansible at high temperatures, and boiling at a low temperature, its use is limited. Mercury expanding more uniformly than perhaps any other liquid, and retaining the liquid form through a great range of temperature, is better calculated for ordinary use than other liquids. To measure temperatures above that of boiling mercury, recourse is had to the expansion of solids: instruments by which this is measured are called pyrometers.

MOBILITY.

18. Mobility is the capability of being conveyed from one to another part of space. Motion has been defined to be a continued change of space, and rest as the contrary. Universal experience having shown the force necessary to move a body to be proportional to its weight, it has been inferred that by the application of sufficient force all bodies may be

put in motion. As, in the sacred record, the first step in the creation is represented as the moving of the Spirit upon the face of the waters; so, without motion there could be neither life nor any of the terrestrial or celestial phenomena, but all things would be in unending sleep or death. Rest, or continuance in place, is to be considered only as apparent or relative to other bodies; for all bodies, independently of their motion with the earth on its axis and in its orbit, are perpetually experiencing change of location, in consequence of the various influences of surrounding objects, as well as their own expansion and contraction caused by changes of temperature. As motion can be described only by reference to objects indicating location, or to some particular kind of motion selected as a standard, and no part of the universe being known to be at absolute rest, and so fit to compare the condition of other bodies with; we may have an abstract idea of absolute motion, which refers to universal space, but are totally unable to describe it. Relative motion may be described in either of the ways indicated. Two bodies may be relatively at rest, and yet have as to a third body a common relative motion. A ship sailing with the tide, or against the tide but with a different velocity, has motion relatively to the bottom and shore; but if she sail against the tide just as fast as the tide runs, she is at rest relatively to them. A man sitting on the deck of a vessel propelled over water has rest relative to the vessel, and motion common with it and relative to the surrounding objects.

Motion may result from the action of a single force, or from the resultant of several forces, and being effected in a straight course is called rectilinear motion; or it may result from the co-operation of a simple impulse, which alone would produce equable motion, with an accumulative force, which tends to produce, in a different direction, motion whose velocity increases in every successive period of time.

If the paths in which the body would be impelled by these forces in one period of time be represented by two sides, A B and A C (Fig. 11) of a parallelogram, its diagonal, A D, will represent the course of the body moved; as in the next period the body is supposed to be moved by one force as far as

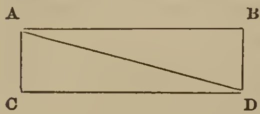
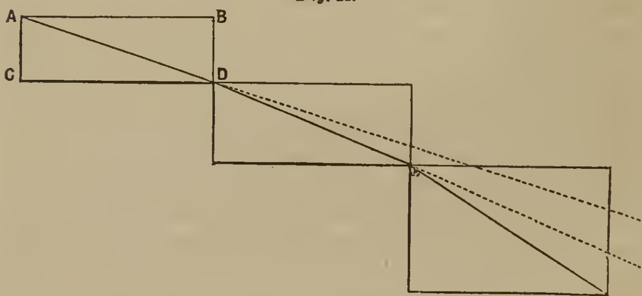


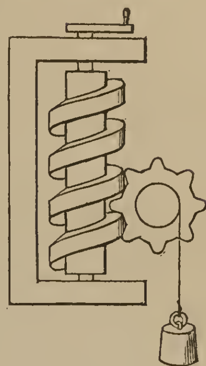
Fig. 11.



in the first period, but by the second force to a greater distance than before, it is manifest that the parallelograms and diagonals, as in figure, must differ, and likewise the direction of the body moved: the same will be true of every successive period; and these periods being indefinitely small the course of motion must be a curve. Such motion is called *curvilinear motion.* The degree of curvature will depend upon the proportion of the two forces. It may be continued, *i.e.* pursuing the same straight or curved course without deviation; or it may be reciprocating, *i.e.* passing forward and backward over the same track. Bodies thrown up or falling perpendicularly through the air, or sliding over an inclined plane, afford illustration of continued rectilinear motion. This kind of motion is of very limited application to machinery; these usually partaking somewhat of the nature of curved motion, *e.g.* the motion of bands con-

necting wheels, and of the cords of pulleys, is a union of the rectilinear and curvilinear motions. Continued curvilinear motion is observed in the actions of the wheel and the endless screw. (Fig. 12.) The saw of a saw-mill, and the piston of a steam-engine or sucking or forcing pump, have a reciprocating rectilinear motion; whereas the motion of the pendulum, of the beam of a steam-engine, or of the handle of a sucking pump, is reciprocating curvilinear.

Fig. 12.



Though motion may be abstractly considered independently of time, yet in all descriptions of motion the idea of time is perhaps necessarily involved. Most of our own actions, as well as those of bodies around us, being greatly and constantly disturbed by extraneous influences, they cannot be taken as measures of time; but certain operations of nature never appearing to be so influenced, their circumstances seeming to be unvarying, are assumed always to occupy equal portions of time and have been employed as measures of it. Thus the flowing of portions of sand through a tube of glass (Fig. 13) and the vibrations of a pendulum (Fig. 14) have been used as measures of short, and the revolutions of the moon as well as those of the sun upon its axis or in its orbit as measures of protracted periods. But in reference to motion time is always considered in connexion with the space traversed. The

Fig. 13.

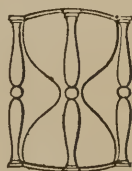
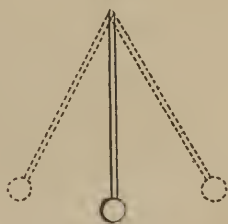


Fig. 14.



relation of space to time is called velocity, which can only be accurately expressed by stating the portion of space passed through by the moving body in a given portion of time, as when it is said to have a velocity of two or three feet per second; yet an idea, to some extent accurate though not definite, is conveyed by such expressions as rapid as lightning or slow as a snail.

19. In a non-resisting medium the quantity and velocity of a moving body impelled by a simple force, and consequently with a uniform velocity, the time, space, and momentum (*i.e.* the amount of motion or resulting force) bear certain relations to each other, so that some being given and used as units, the others may be calculated from them. It is manifest that in equal times, the spaces must be equal; but in double the time, the space must also be double, or in general the time varying, the space must also vary, and be as the velocity multiplied into the time; this may be expressed algebraically, thus $S=VT$, for a body moving with the velocity of two feet in one second, must in two seconds move through four feet. The time is ascertained by dividing the space by the velocity: for if the body moving with a velocity of two feet per second passed through twelve feet of space, it must have occupied six seconds, that is twelve divided by two, hence the expression $T=\frac{S}{V}$. In like manner it can be shown that the velocity is ascertained by dividing the space by the time, $V=\frac{S}{T}$. The momentum, already defined to be the amount of motion or resultant force, is equivalent to the impression the body could make upon another body directly in its way. It is ascertained by multiplying its quantity into its velocity, thus $QV=M$: for if a certain impulse can cause a quantity of matter to move with a certain velocity, it can impart

double the velocity to half the quantity, and but half the velocity to twice as much matter: the resistance necessary to stop the body must likewise be proportioned to the impulse, therefore the quantity remaining the same, the momentum will be as the velocity; but with the same velocity, the mass being doubled, there will be double momentum, consequently both quantity and velocity being doubled, the momentum will be quadrupled. As a necessary consequence the quantity of matter equals the momentum divided by the velocity $Q=\frac{M}{V}$: and the velocity equals the momentum divided by the quantity $V=\frac{M}{Q}$. If a non-elastic body A, moving with a uniform velocity, meet another body B of the same description in its way at rest, moving in the contrary direction, or in the same direction with a different velocity, their condition of rest or motion after contact will depend on the circumstances of their momentums. If one be at rest its momentum is nothing, and the joint momentum equals that of the moving body: if both be moving in the same direction, the joint momentum must equal the sum of the previous momentums: and the velocity will, in both cases, be equal to the quotient of the sum of their momentums divided by the sum of their quantities of matter. Letting V represent the velocity of A, and v that of B, their velocity after contact, will, in the former case, be represented by $\frac{AV}{A+B}$, and in the latter by $\frac{AV+Bv}{A+B}$. If however they be moving in contrary directions, action and reaction being equal, the joint momentum must equal the difference of the previous momentums, and the velocity will be represented by $\frac{AV-Bv}{A+B}$: of course, if their momentums

previous to contact be equal, then velocity after contact will equal nothing, and they will remain at rest. We have here considered the body as propelled by a single force, and in the direction in which it acts; but, as already intimated, two or more forces may co-operate so as to form a similar result. The body impelled by two or more forces at the same time, does not move in the direction of either, but in an intermediate one, and at length reaches the point it would attain if the forces acted consequentively. Motion resulting from the concurrence of two or more forces, though it be in a direct line, is called compound motion.

20. Motion is naturally uniform. The motion of a planet being found to have at one time a certain velocity relatively to some other continued motion, they will at any subsequent period be found to have the same relative velocities, or the change will be in proportion to interfering causes: thus the times of eclipses can be accurately foretold thousands of years. The uniform motion of certain mechanical contrivances enables us to measure short portions of time. The uniform motion of the earth upon its axis and in its revolution around the sun, enables us to anticipate future events, they giving us the division of time into days and years, which we use as great standards with which to compare minor occurrences. A lofty spire stands more securely upon the earth than does even a low pillar on a moving wagon, because the motion of the earth is more uniform. It is the uniformity of the earth's motion that renders it imperceptible by us. The case would be the same if it revolved in ten or one hundred hours instead of twenty-four. This natural uniformity of motion causes bodies moving together, as the furniture of a sailing ship, to appear at rest with one another. A person moving with such bodies knows that he moves only by observing his change of direction with surrounding objects.

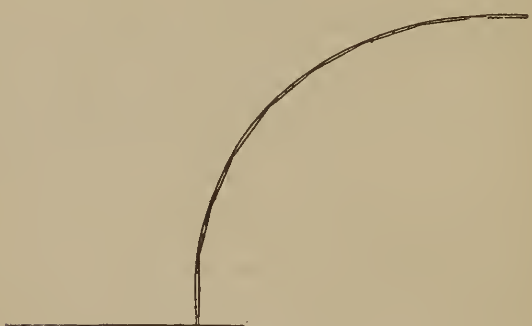
Through the force of circumstances motion may be

variable, unequal spaces being passed through in equal times. Variable motion is either accelerated, the velocity constantly increasing; or retarded, the velocity constantly diminishing. Motion in falling bodies is accelerated by gravity, they every moment receiving from this cause a fresh velocity. The eye perceiving an apple beginning to fall can for a time mark the gradual acceleration of its descent, but soon perceives its track only as a shadowy line. A boy can catch his ball the instant it falls from his hand, but after a little delay he will pursue it in vain. A fragment of rock detached from the brow of a hill moves, at first slowly, but with greater speed every instant, till it drives every article before it. Though each vibration of the pendulum is performed in equal portions of time, the different parts are performed in unequal periods, its descent, like that of all other falling bodies, being accelerated by gravitation. A liquid, *e.g.* molasses, falling from a reservoir forms a stream, the bulk of which diminishes as the velocity increases, becoming finally a fine thread, but rapidly filling a receiving vessel; so at the Falls of Niagara, the river appears at the top an immense slow, moving mass, descending it becomes thinner and thinner with increasing velocity, till at last almost reduced to a mist, it moves with the velocity of lightning. If the velocity of a body be very great, it cannot be determined by the sight, but it can be estimated by the effect of its impulse upon other bodies; thus a man may jump from a chair without inconvenience; and from a table with a jar; if from the top of a house his bones may be broken; if he fall from a balloon he will be dashed to pieces.

Gravitation is a force continually acting, hence a body falling through its influence alone, and without obstruction, would have its velocity increased every successive instant. The acceleration of velocity is stated to be as the squares of numbers representing equal periods of time during which a body falls. The force of gravity at the earth's sur-

face has been found to be such, that a body will in one second of time fall 16 feet, and in that time it acquires a velocity which of itself would carry it during the next second through 32 feet, and during this second it also is drawn downwards by the force of gravity 16 feet more; so that in that second it moves 48 feet; of course, during the first two seconds it falls 64 feet; its velocity alone would now carry it 64 feet in a second; but the gravitation gives it an additional velocity of 16 feet; it therefore in the third second moves through 80 feet. Thus in the three seconds it moves through 144 feet. A body passing down an inclined plane will move with a velocity greater as the plane approaches more nearly the vertical position; because the obstruction of the plane independently of friction is thus diminished; the motion will be less rapid, but accelerated according to the same laws as of bodies falling without hindrance. In these two cases the velocity of the moving body increases in a regularly progressive ratio; that of a body moving down a curved surface, will also be accelerated, but in an irregular manner. The curved

Fig. 15.



surface may be considered as made up of a succession of inclined planes, each, if the surface be convex, steeper than

the preceding, and of course presenting less resistance to the gravitation of the descending body, whose velocity will therefore increase in a greater ratio than if the surface were plane. (Fig. 15.) If the surface be concave, then the supposed planes will be successively less steep, and will offer increasing impediment to the progress (Fig. 16) of the

Fig. 16.

descending body; but not sufficient without the aid of friction to prevent entirely the increase of velocity.

21. Retarded motion is that in which the velocity is continually diminishing. The laws of retarded motion are the reverse of those of accelerated motion. The velocity necessary to be imparted to a body at rest, in order to carry it vertically upward to any assumed distance, is the same as it would acquire by falling the same distance. As it ascends its progress is retarded by the same cause that would expedite its descent; thus a body being propelled vertically upward by a force which would carry it 144 feet in three seconds, its velocity may be represented by 144: during the first second it will lose 80, when it will retain a velocity of 64, of which 48 will be expended in carrying it through the next second, leaving only 16 for the third second. A ball shot perpendicularly upwards at length reaches a point where it might be for an instant in contact

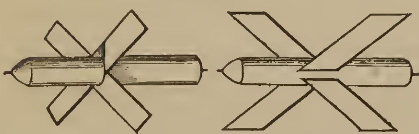
with a bird without inflicting any injury, its velocity being in the second instant of its passage but one-quarter, and in the third but one-ninth of what it had in the first, &c. As the passage of a body down an inclined plane is less accelerated, but the velocity ultimately acquired is the same as if it descended perpendicularly: so one ascending such a plane has its velocity exhausted at the same vertical height, but more equally as the plane is less vertical. Also bodies ascending a convex surface are retarded progressively, but less rapidly as they advance, the chords of the arcs being each moment more horizontal. On the contrary, one ascending a concave surface suffers retardation in degrees increasing each moment, because the chords of the arcs are successively more vertical. For this reason the velocity of the pendulum diminishes as it ascends, until it completes its vibration at the same height as that from which it fell.

If a moving body come against a spring, or a bladder filled with air, or against the piston handle of an air syringe, so as to compress the air beneath, its motion will be retarded by repulsion.

Motion is as naturally permanent as rest. A contrary opinion is common, because we see most bodies in a forced state. Jupiter's satellites have revolved with uniform velocity around him; so the moon has moved around our globe, and both the planet and earth with their moons have passed uniformly for thousands of years in their orbits. Things may float in a trough on a sailing vessel without approaching the end nearer the stern; and those floating on streams do not accumulate on the western banks, as would occur, if all bodies tended to rest. There are great differences in the duration of motion among bodies on the earth's surface, but exactly in proportion to evident causes of retardation, of which are friction and resistance of water and air. Friction is the resistance which one body offers to another rubbing upon it; it differs greatly in different cases,

as is illustrated by a ball set in motion by equal forces, rolling to a greater distance over cloth spread on a smooth plank, than over grass, and to a still greater distance over a bare plank, and being scarcely retarded on smooth ice. Friction may be greatly diminished, but never entirely overcome by art. Sharp bodies pass more readily through water than blunt ones. Fishes, owing to their sharp extremities, swim with facility. The passage of birds through the air is facilitated by their having a shape somewhat similar to that of fishes. That calm air resists motion may be shown by setting in motion, together, two miniature windmills, one with the flat sides and the other with the edges of the vanes in the direction of motion, in air and in vacuo; that with the edges in the course will move much longer than the other, whereas in vacuo, both will stop together. (Fig. 17.) A pendulum, having only a slight friction at its point of suspension, will, if put in motion in vacuo, vibrate a day or more.

Fig. 17.



INERTIA.

22. Inertia is the want of power in matter to change its condition of rest or motion. It is sometimes called stubbornness, sluggishness or inactivity. Indeed the word inertia signifies inactivity, and refers to the resistance overcome in putting a body in motion or in stopping one moving. This resistance is the reaction or counter force exerted against the acting body, and is increased by the addition of matter; thus a vehicle may be readily moved by an agent

but by increasing the load it may become incapable of being stirred by the same agent; universal experience proving that the quickness of a moving body is proportioned to the force by which it is moved, and that its progress is retarded in proportion to obstructions encountered; whence it has been concluded that a body at rest, and receiving no impulse, would never move; or being in motion if it met no obstruction, would never come to rest, but would continue to move for ever without change of velocity or direction. A hand being applied to the crank of a grindstone and an exertion being made, it is set in motion; now, less exertion need be made to stop it gradually, because the friction and resistance of the air opposes the first exertion, but favors the second. To stop a roller revolving on a smooth surface, allowing for the friction and atmospheric resistance, the same exertion must be made as was first used to set it in motion.

Force has been defined "whatever produces or opposes the production of motion." That a moving body, not acted on by any force, will go on perpetually in a straight line and with an uniform velocity, was not credited from the time of Aristotle to that of Galileo; and, even now, the opinion of men is contrary thereto, till their attention is directed to the hindrances a moving body invariably meets, and which are really the causes of the retardation: It was shown to the Royal Society, while the matter was under investigation, that by increasing the weight of a top and diminishing the resistance offered by its support, it could be made to spin much longer than otherwise it would, and consequently it is friction against the support and resistance of the air, and not any principle within it, that destroys the motion. These impediments to motion cannot be entirely removed, but have been so to an extent sufficient to show that if all resistance were removed motion would be perpetual. Historically it is true that the knowledge of this

law is the result of observation; but it has been contended, with appearance of much probability, that the law is more consonant with our ideas than any other would be, it depending to some extent on the axiom that no change can occur without cause. The amount of inertia determines that of the force required to give motion to or destroy it in a mass: so the amount of inertia may be determined by that of forces: *e.g.* the force of the earth's attraction acting for one second, causing a body to fall 16 feet, overcomes its inertia to that extent; were the inertia reduced to one half, the body would fall 32 feet in a second; and if it were entirely overcome, the body would fall any distance, however great, in an instant. A heavy cannon ball, with its present inertia, requires pounds of powder to give it its usual motion, and that motion may not be overcome by blocks of granite, which it shivers to pieces; but if the inertia were absent it might, with the slightest force, be propelled with inconceivable velocity, and yet the resistance of a hair be sufficient to stop its progress. Force that can be employed in producing motion, *e.g.* muscular effort, the unbending of a bow, or the impulse of a moving body, is called *active force* or *power:* what tends to stop a moving body, to drive it back or otherwise change its course, is called *resistance:* and force which can never be used as a power is called *passive force*, *e.g.* the suspension of a weight by a rope, or its support by a table.

23. Power may be *impulsive*, *i.e.* its whole effect may be produced in an instant, as where a body at rest, *e.g.* a ball, is set in motion by momentary contact with another body in motion; or it may be *incessant*, *i.e.* continuing after the first moment of its application, as the force of gravity. Incessant force may be *constant*, *accelerating*, or *retarding*. *Constant force* is that which in equal times produces equal increment or decrement of motion, *e.g.* pressure. *Accelerating force* is that which produces a pro-

gressively increasing velocity: *e.g.* the attraction of the earth which causes the descent of the pendulum or of other falling bodies. The action of gunpowder on a ball, though apparently instantaneous, is accelerated through the length of the weapon: hence long cannons are more effective than short ones. Some long-necked birds kill their prey by drawing back their heads and then darting them forward by continued muscular action till they acquire almost the velocity of a bullet. The accelerating force of muscular action enables the kicking horse to strike a distant object with much greater violence than one nearer by. A bow-string being released from its state of tension, acts as an accelerating force upon the arrow which it propels, imparting to it the velocity it has at last acquired. The human breath acting as an accelerating force upon a small object passing through a long fine tube drives it forward with considerable violence. *Retarding force* is that which impedes or overcomes motion. What accelerates one motion may retard another, *e.g.* water free to move is accelerated downwards by gravitation; but an upward jet is retarded and sometimes spread out like a palm tree, and its progress entirely destroyed by the same cause. A vast rock suspended like a pendulum descends with augmented velocity to the bottom of a curve: whence it ascends, its progress being retarded in an equal degree, and by the same gravitation which accelerates its descent. Air by expanding accelerates motion; yet the same air encountering a moving body will retard its motion: if a cannon ball could be fired into a long close tube of proper dimensions, its progress would be gradually annihilated. Resistance overcomes motion more effectually as it is gradually offered, *i.e.*, as it partakes more of the nature of retarding force: thus cotton bales on the side of a vessel offering a gradually retarding force to a cannon ball will bring it to rest without being much injured, while the firmer side of the ship offering in-

stantaneous resistance will be shattered without stopping the ball. A hempen, silk, or cotton rope will resist a greater weight thrown into a scale supported by it than could an iron chain which would sustain quiescently an equal weight; yet a rope will not so well retain a ship at anchor as a chain of equal sustaining powers, because the rope being of nearly the same specific gravity as water, will be stretched in a straight line, and offer but simple resistance to the impulse of the waves; while the chain, in consequence of its greater weight, will hang as a curve and act as a retarding force upon the same impulse. Traction made upon one end of a rope which revolves around a block, will set in motion a large ship to which the other end of the rope is attached: a rope so attached will retard and finally stop a vessel in full sail, if occasionally relaxed so as to slide over the block.

Action and reaction are always equal and contrary to each other; which of two bodies will move depending on the attendant circumstances; thus two bodies moving in contrary directions and their momentums being equal will be both brought to rest, but the momentum of one being greater both will move in the direction of that one, but with a diminished velocity. Action and reaction can be illustrated by pieces of loadstone and iron placed upon corks floating on water; both being free to move they will approach each other and meet at some point between their original positions, but either being confined to its place the other will approach it.

The following are illustrations of inertia. A ship does not acquire her full speed at once upon spreading her sails, but as the continuing force overcomes her inertia; so her motion is not lost immediately upon taking in her sails, but as the continued resistance of the water destroys it. Horses having to overcome the inertia of rest in a carriage, must make a greater effort to set it in motion than to maintain the motion; and if the carriage be on springs, on the first

motion its body and contents appear to be thrown back; because the inertia of the wheels is first overcome. Owing to its inertia, a strong effort is needed to stop a moving carriage; and upon stopping it, the body and its contents move forward. A man standing upon a boat or waggon is in danger, upon its moving forward, of being thrown out backward; because his feet move forward, while the inertia of his body keeps it in place; upon stopping, his feet being brought to rest, while the inertia of his body carries it on, he is in danger of being thrown forward. A man jumping forward from a carriage in rapid motion, is in danger of falling, if he does not advance his feet as in running; because his feet come to rest upon the ground while his body advances with the velocity of the carriage; if he jump backward he is almost certain to fall, because his head moves forward with the velocity of the vehicle, while his feet move backward. A person by running overcomes inertia, and is thus enabled to leap over a chasm more easily than he could if standing. If a vessel full of water be suddenly pushed forward, part of the water is left behind; if it be suddenly stopped, when in motion, the water is thrown forward. A coin being laid on a card balanced on a finger, a slight blow on the edge of the card will carry it forward, while the inertia of the coin will retain it at rest.

ATTRACTION.

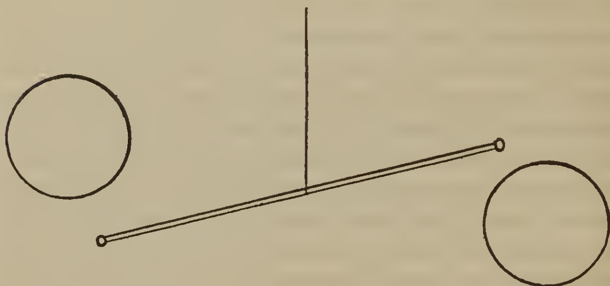
24. This term is applied to the supposed cause of perhaps the most extensive generalization ever attempted in natural science, viz. that all portions of matter in the universe tend to approach each other. Attraction is considered as occurring at sensible distances, or only where the bodies reacting are in apparent contact; and both these classes are subdivided: to the first class belong attractions of gravita-

tion, magnetism, and electricity, and to the second cohesion, adhesion, capillary attraction, and chemical attraction.

Gravitation is that form of attraction which draws all terrestrial objects towards the earth's centre, and it, as well as the other parts of the solar system, towards the sun. Probably everything within the universe is influenced by this attraction; and beside being drawn toward the great or the lesser centres all influence each other; thus the attraction of the moon causes the rising of tides, and the sun and moon co-operating produce the high or spring tide. This force causes the earth and the heavenly bodies to retain their forms, notwithstanding the tendency to fly apart which would be imparted to them by their revolutions. Their being all of a globular form has been considered a proof of their all having been once in an aeriform or liquid condition. The generally received hypothesis respecting gravitation views it as an essential property of matter; other hypotheses, however, have been advanced; *e.g.* it has been referred to the elasticity of an ether, also to the impulse of streams of particles constantly flowing in all directions through the universe. All the physical properties of matter have been attributed to the emanation of attractive and repulsive forces from collections of points. It has been objected to this last view that a body cannot act where it is not; but it is replied, that there is no visible necessity of continuity, all that is necessary being the equality and opposition of the action and reaction. Modern philosophers are agreed that gravitation affects all kinds of matter in the same manner; that is to say, its force is in all cases directly as the quantity of matter, and inversely as the squares of the distances from the centre of the attraction. Prior to the adoption of these rules it had been conjectured that the sun's attractions were inversely as the distances; this idea being probably suggested by another, that attraction might be viewed, like light, as an emanation from a

centre, becoming weakened as it recedes from the centre. That all bodies attract each other at sensible distances is shown by a celebrated experiment: a very light deal rod, with a small metallic ball at each end, was suspended horizontally at its centre by a fine wire. Having oscillated some time, by the untwisting and twisting of the wire, it came to rest. Two large spheres of lead were brought into such positions that if one could attract the small ball near which it was placed, the other, by its attraction for the other

Fig. 18.



small ball, would augment the effect. (Fig. 18.) A very decided motion was so produced. By observing the extent of motion, and the times of the oscillations consequent upon withdrawing the globes, the proportions between the effect of the elasticity of the wire and the attractions of the globes for the balls were determined: by a series of experiments, not the only actual influence of gravitation on terrestrial bodies, but its relative influence as depending on the density of the attracting body and the mean density of the earth have been decided.

The attraction between bodies is in proportion to the masses; hence the motion of the earth towards bodies falling upon it is so minute as to be infinitely beyond the limits of our observation. The overpowering influence of the earth's attraction causes the seeming inactivity of bodies

at rest on its surface. A small particle of matter being placed on the surface of a golden globe one foot in diameter, the force by which it is attracted towards the gold is less than $\frac{1}{10,000,000}$ that of its gravitation towards the earth; because the diameter of the earth is more than 41,000,000 feet, and the density of the gold is about four times the mean density of the earth; hence the particle in one second will approach the gold globe less than $\frac{1}{10,000,000}$ of 16 feet, a space entirely imperceptible. Hence we cannot directly compare the gravitative force of detached masses and of the whole globe; yet large mountains do draw aside bodies from the direct line of the earth's attraction. Some French academicians, about the middle of the last century, with the view of ascertaining a meridian in Peru, were engaged in determining the zenith distance of a star. They found the plummets of their quadrants on the opposite sides of a mountain were attracted towards the mountain, making the zenith distance greater than it ought to have been. In 1772 this phenomenon was confirmed at the mountain Schehallien, in Perthshire, Scotland, the deviation being found to exceed seven seconds. Weight is the measure of the force of gravity on a body, and is proportional to the quantity of matter in it. Gravitation is inversely as the distance from the centre of the earth. Under ordinary circumstances the diminution from elevation is too small to be perceived; yet by experiments with a spring balance in a balloon, or on a very high mountain, a body weighing 1000 pounds at the level of the sea has been found to lose five pounds; and from astronomical observations it has been calculated that it would weigh but five ounces if at the distance of the moon. A difference has even been found in different latitudes; thus bodies weigh less near the poles than at the equator. The direction of gravitation is ascertained by the plumb-line. Being towards the centre of the earth, any two such lines must always form an angle; and if the point of

observation be very distant on the surface of the earth, or if they be considered as continued to a great distance upward, the angle would be quite conceivable; but for any neighboring spots, the difference in direction is too slight to be perceived; and the plumb-line is always viewed as perpendicular to a horizontal plane at the place of observation. In every body there is a point towards which all its particles, in consequence of this attraction, tend; so between any two, or among any number of bodies, there is a similar point, at which, but for opposing causes, they would be accumulated; and if these bodies be supported at that point they will balance; and for all statical purposes they may be considered as collected at that point; for they will there exert a pressure equal to their combined weights. This point is called the *centre of gravity*, and is always at the lowest point possible under the circumstances.

25. *Magnetic Attraction.*—A loadstone is capable of attracting to certain points on its surface called poles light particles of iron, and retaining them there. A bar of iron which has been magnetized exerts the same force at points near its extremities, which points are likewise called poles. When such a bar, which is called a magnet, is left free to move, one extremity of it is so attracted by the north pole of the earth as to point in its direction. This point is usually called its north pole; the other end, pointing equally south, is called its south pole. If the north pole of one magnet be brought near the south pole of another magnet they will move towards each other.

26. *Electrical Attraction.*—If a rod of glass be rubbed with warm silk it will attract many light bodies. If a stick of resin be treated in the same way it will acquire the same property. Several bodies which have been so attracted by glass will not attract each other; neither will those which have been attracted by resin; but those which have been attracted by the one will attract, or be attracted, by such

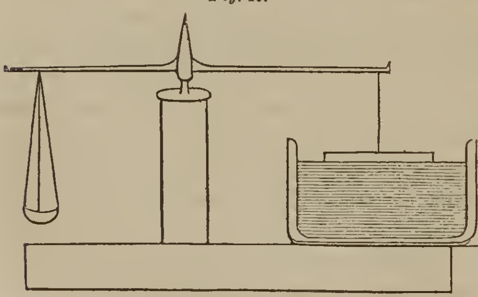
as have been attracted by the other, or such as are unexcited. In general, those which are differently excited attract each other. By the electro-torsion balance it has been ascertained that the times of vibration are directly proportioned to the distances, whence it follows that the force of the attraction is inversely as the squares of the distances.

27. *Attraction of Cohesion.*—Cohesive attraction, or cohesion, bearing either of these names, is the form of attraction which, acting at insensible distances, unites particles of the same kind of matter, whence it is also called homogeneous attraction; and, causing it to exist in masses, it is called attraction of aggregation; and, as forming bodies, it is called corpuscular attraction. It is thought to be simply a modification of gravitation. Though it is at first incredible that the same cause which attracts a mass of iron to the earth with only the force of its weight should attract the particles together with the force by which they are retained in mass, the difficulty will vanish when it is recollected that the atoms may be a million of times nearer when in apparent contact than when one-fourth of an inch apart, and that the energy of gravitation is inversely as the squares of the distances. Were it not that only a very small portion of their particles can touch each other, bodies of a similar nature would invariably cohere when brought into contact; hence two smooth panes of glass or slabs of marble, of which perhaps only a few points in a million are in contact, cohere with great pertinacity. Two fresh-cut surfaces of caoutchouc pressed together will cohere almost as firmly as the particles of either piece do to each other. Two leaden balls, having similar portions cut off with a clean knife, and then pressed firmly together by a slightly twisting force, will cohere.

Cohesion, though but in a slight degree, does exist in liquids. The round form which they assume when small in bulk, and on a surface which is not moistened by and exerts

no chemical action on them—*e.g.* mercury on a plate of iron, glass, china, or marble, and drops of dew or rain on certain leaves, is generally attributed to action of this force—and the difference in the size of drops of different liquids to the difference of their cohesive attraction; 60 drops of water will fill as much space as 100 of laudanum. As the mass increases the liquid yields somewhat to gravitation, and acquires a surface more or less level. Liquids poured slowly from a vessel pass in a continued stream, because the several particles have too much cohesion to separate themselves. If no cohesion existed between the particles of liquids—*e.g.* mercury or water—they would fall like dust. The particles of water cohering prevent a needle, gently laid on it, falling through. A flat piece of any material capable of being wet by water, if balanced from the end of a weighing-beam and then brought into contact with that liquid, will adhere to it with a force more than equivalent to the water remaining on it when they are separated, the attraction of the solid for the liquid being greater than that of the parts of the liquid for each other; liquid is separated from liquid. It has been proposed to apply this property to the determination of the cohesive force of liquids; a plate capable of being moistened by several liquids is suspended from one end of a very delicate balance, so counterpoised that a very slight weight will cause a preponderance; the liquid is now brought into contact with the lower sur-

Fig. 19.



face of the plate, and weights are added to the scale at the other end till rupture takes place. (Fig. 19.) The weights indicate the force of cohesion for a surface of the liquid equal that of the plate. The cohesion of water being 414·7, that of oil of turpentine with s. g. 0·8695 is 523·6 as indicated by glass. Though with the same liquids and solids the results are uniform, yet mercury with different solids gives very different results, showing that the cause is more complex than simple cohesion; thus with gold the force appears to be 23·63, while with copper it is but 7·52.

28. *Adhesion* is that form of attraction by which particles of matter of different kinds are retained in contact when once brought sufficiently near. It is called "heterogeneous attraction," because it is exerted between bodies of dissimilar natures.

I. Adhesion of solids to solids. This kind of adhesion is illustrated by amalgam of tin in reflectors, adhering to the glass. Gold leaf smartly hammered against clean steel adheres to it. Wax adheres to many surfaces, *e. g.* wood; hence its use in polishing furniture. Fats adhere to most solids, and hence are often great hindrances in many operations. Many precipitates adhere tenaciously to glass vessels; so that failing by friction, it is often necessary to remove them by solution.

II. Adhesion of liquids and solids. Upon plunging a piece of glass into water or alcohol, and then drawing it out its surface will be found wetted by a retained portion of the liquid. A clean surface of metal, *e. g.* of copper, being placed on one of mercury, a force varying with the metal will be required to separate them, and upon being separated a portion of the mercury will be found adhering. The liquid molecules are in these cases separated because the cohesion is less powerful than the adhesion. Pouring of liquids from vessels depends upon the influence of gravitation; to favor which is the use of lips to the vessels; some-

times the lip is so much rounded or so short, that the adhesion of the liquid to the solid causes it to flow along the side of the vessel in an upward direction. This property may be applied to directing liquids along the under side of rods to any desired point. A thin layer of liquid interposed between two solids may adhere, by its opposite surfaces, to both solids; thus two coins or two panes of glass may be held together by a thin layer of water, the force of adhesion is sometimes so strong that if one of the solids be fixed the adhesion will entirely overcome the force of gravitation upon the other. The mobility of the particles of liquids renders it easier to exhibit this property in them than in solids; but for the same reason it is less energetic in liquids, as by solidifying the interposed layer the adhesion is greatly increased; thus a layer of warm fat between two plates will adhere, yet allow them to slide on each other; but upon its solidifying considerable force will be necessary to separate them. This is also exhibited in the junction of two bodies by a cement, *e. g.* two pieces of wood by glue, bricks or stones by mortar, and porcelain by albumen and lime; the cement as it hardens draws the surfaces together so powerfully that they will suffer fracture sooner than be separated at the place of juncture: the adhesion of glue to glass also is so great that portions of glass are torn off in attempts to disengage the glue. Liquids differ in their power of adhering to the same solid: hence a drop of alcohol or of oil of turpentine can drive a film of water from the surface of glass, marble, or silver. The weights of porous bodies and powders are considerably increased by moisture attracted from the air: a circumstance demanding attention in organic analysis. Adhesion is modified in so many ways that it is impossible accurately to measure its force: yet it has been proposed approximately to accomplish this end: thus, into an end of a glass or porcelain tube capable of resisting a pressure of more than 100 pounds to

the square inch a plug of dry wood has been tightly fitted, of which a projecting portion has been dipped into water; by the swelling of the wood the tube has been burst. It is however clear that it is by no means adhesion alone which causes the rupture. The same complex force has been applied to split rocks: dry wooden wedges driven into holes bored in the rocks are wet with water, and swelling, split them as desired. A piece of glass or iron being immersed into mercury, upon removing it, none of the fluid adheres; this has been attributed to the entire absence of attraction between the solid and liquid molecules, or to its being less powerful than their cohesion: but that, at least, from between mercury and glass this attraction is not entirely absent is shown by the following experiment; a barometer tube seventy inches long being thoroughly cleansed and freed from closely adhering air, as by the action of alcohol, and then filled with pure mercury, also freed from air, and turned with great care so as to immerse its open end in mercury, the whole column will remain in the tube, and will require several slight agitations to cause its descent to the barometrical height. The want of adhesion between fat and water facilitates the pouring of that liquid from vessels with defective lips: the lip being greased prevents the water running down the outside of the vessel.

29. *Solution* is a process in which a solid body is diffused through a liquid, losing entirely its solidity. It is analogous to adhesion. The liquid is called the menstruum or solvent. If a lump of sugar or salt be suspended with small points in contact with water, the water will adhere and rise through the pores, dissolving out the cement (saccharine or saline) which holds the little crystals together; and these will fall, their particles being in like manner disintegrated will be attracted by the liquid, and will rise in it as far as the adhesion of the particles of liquid already in contact

with them and gravity will allow. A stratum of the solution will remain below until it be mechanically diffused though the water, when the salt or sugar will be retained in all parts by adhesion. For a fixed quantity of the solid to be dissolved, an indefinitely large quantity of the solvent may be employed: yet there is a limit to the exercise of adhesion, as is shown by the phenomena of saturation. Thus one hundred parts of water may dissolve any number less, but not more, than thirty-seven parts of salt; the adhesion of the water to the salt progressively overcomes the cohesion of the solid till the two forces are balanced, when the fluid is said to be saturated. The power of water to dissolve different soluble substances, is very various towards the different articles, but fixed as to each individual. The power of saturation is not dependent on the atomic weight of a solid; indeed in many instances it varies greatly with the temperature; hydrated salts (those containing water of crystallization) capable of undergoing watery fusion above the temperature necessary thereto, dissolve in any proportion of water. Generally the most fusible salts are most soluble; *e.g.* hydrated salts, and of anhydrous salts, chlorates, nitrates, chlorides, and iodides, all of which are highly fusible and soluble. Cohesion is the only property of bodies which is materially affected in this kind of combination, and it is probably by diminishing it that heat favors solution. Common salt is equally soluble at all temperatures. The solvent power is sometimes diminished by a high temperature; *e.g.* sulphate of soda at 32° F. 100 parts of water dissolve 5 parts, at 92° 52 parts, and at higher temperatures the quantity dissolved is progressively lessened till at 230° they dissolve but 43 parts. Solvents dissolve most readily those substances which they most resemble in properties; thus, mercury is perhaps the only solvent of metals; oxydated solvents dissolve oxydated bodies, *e.g.* water dissolves acids and salts; substances abounding in hydrogen,

are most readily dissolved in hydrogenated liquids, *e.g.* fat or resin in oil; essential oils, most organic elements, and but few oxysalts in alcohol and ether. The solution of a solid is greatly hastened by previously pulverizing it. This is due to the increased surface which is thereby presented to the action of the solvent.

The cleansing property of water is owing to its power of adhesion or solution. Alcohol dissolves some bodies, *e.g.* resin, which water does not; and water some, *e.g.* gum, which alcohol does not. Sometimes the mutual attraction of two liquids is greater than the adhesion of either to a solid soluble in it; in that case if one of the liquids be added to a solution of such solid in the other, the solid will be separated, when it is said to be precipitated, *e.g.* gum is separated from water by alcohol, and resin from alcohol by water.

30. III. *Adhesion of liquids to liquids.*—A very small quantity of oil placed on water is diffused over the surface in a very thin film presenting a variety of hues; the quantity of oil being increased, its cohesion overcomes the adhesion, and the oil collects into a lenticular mass. A plate of glass being covered with oil, and then laid with its oiled surface upon water, to remove the glass perpendicularly upward will require considerable force. In other cases the particles of the different liquids adhere so as to be diffused through each other, as in the dilution of alcohol or acids by water.

31. IV. *Adhesion of gases to solids.*—Fine particles of iron, mercury, or lead, etc., thrown upon water, have air adhering to them, which prevents them sinking until they collect in sufficient quantity and contiguity to become specifically heavier than water, when they sink. Upon pouring mercury into a glass tube closed at one end, bubbles of air are observed to adhere to various portions of the glass, although encompassed by a fluid more than 11,000 times as heavy as itself. Water boils at a lower temperature in a

metallic vessel than in one of glass, owing, as it is supposed, to the adhesion of the vapor to the glass surface. Box-wood charcoal, free from air and moisture, will, in 24 hours, absorb 35 times its bulk of carbonic acid, the whole of which cannot be removed by an air-pump. If a stream of hydrogen gas be thrown upon spongy platinum in air, it adheres to the platinum, which instantly becomes red-hot, and the hydrogen is ignited. The same effect is produced by introducing a perfectly clean plate of platinum into a mixture of hydrogen and oxygen gases. When the oxide of iron is reduced by hydrogen, a quantity of the hydrogen adheres to the iron, and causes it to burn immediately on coming in contact with the air. The previous pulverizing of the solid, favors these actions by presenting increased surfaces to the adhering gases.

32. V. *Adhesion of gases to liquids.*—Gases and vapors are absorbed by liquids, but in general not to as great extent as by some solids; thus of oxygen gas, water absorbs 0.045, alcohol (*s.g.* 0·84) 0·1625 and charcoal 9·25; of hydrogen gas water absorbs 0·0156, alcohol, 0·051, and charcoal, 1·75; of carbonic acid gas, water absorbs 1·06; alcohol, 2·6; spirit of wine, 1·87, and charcoal, 35 volumes; in some cases the liquid absorbs a much larger bulk, *e. g.* of hydrochloric acid gas, water absorbs 480 volumes, while charcoal absorbs but 85; of ammoniacal gas, water absorbs 670, and charcoal but 90; of sulphurous acid gas, water absorbs 43·78, charcoal 65, and alcohol 115·77; the temperatures at which these results were obtained having been somewhat different, they are but approximate. In general, the absorbing power of different liquids is inversely as their specific gravities; but this is very far from being an exact law. Silver, when melted in air or in oxygen gas, absorbs a large quantity of gas; which upon the solidifying of the silver escapes, giving to the button a jagged or arborescent appearance.

33. VI. *Adhesion of gases to gases.*—Cohesion appears to be entirely wanting in gases, the particles of any one kind of gas being kept in contact only by some extraneous force. The molecules of different kinds of gases, however, exert towards each other a kind of attraction analogous to adhesion, which is usually called *diffusion.* If two liquids which do not react chemically, *e.g.* oil and water, or mercury and water, be commingled, they will, upon being left at rest, separate, the heavier occupying the lower position; not so with gases—which not only do not separate when so commingled, but tend to mix even contrary to their specific gravities. So great is this tendency with oxygen and hydrogen, that, if they be contained in separate vessels united by a tube of only one-fourth of an inch diameter and three feet long, the oxygen being in the lower vessel, and sixteen times as heavy as the hydrogen, they will, in a few hours, be found to have commingled. The same is the case with all gases which exert no chemical action on each other at ordinary temperatures. It was first observed that, upon passing a gas through a stone-ware tube in a fire, the gas, although under pressure, escaped through the pores in the tube into the fire; and gases from the fire passed into the tube. It was afterwards discovered that, if the upper of two vessels, placed vertically over the other, and communicating by a fine tube, contain hydrogen, and the lower carbonic acid, these gases will be found to interchange places although the latter is twenty-two times the heavier. This disposition is so strong that many philosophers consider one gas as offering no greater resistance than a vacuum to the expansion of another. Subsequently, by allowing different gases to diffuse into the air, through a fine tube, in a way not favored by their gravity—*i.e.* the gases heavier than air from the top of the vessel, and those lighter from the bottom—it has been found, 1st. That different gases escape with rapidities various, but bearing some relation to

their specific gravities, the lighter gases diffusing much more rapidly than the heavier. 2d. From a mixture of two gases, the more diffusive escapes more rapidly. This furnishes a method of mechanically separating gases—viz. allowing the mixture to diffuse, for a limited time, into a confined gas or vapor of a kind capable of being easily condensed or absorbed. Diffusion of gases is best illustrated when they communicate through pores of insensible magnitude. A chemist, in collecting some hydrogen gas, accidentally used a cracked jar; after twenty-four hours, during which neither the pressure nor temperature of the atmosphere had sensibly changed, he observed that the water had risen two and a half inches above the level of that in the trough. Another, repeating and varying the experiment, using more accurate instruments, found that not only did hydrogen escape, but air entered; but the bulk of the escaping hydrogen was 3·83 times as great as of the air entering. He ascertained that of each gas a peculiar volume would escape in a fixed time; this he called its *diffusion volume.* He further ascertained that the diffusion volumes of any two gases are universally as the square roots of their specific gravities.

Many porous substances—*e.g.* charcoal, wood, unglazed earthen-ware, dry bladder, thin slices of granular foliated minerals, as flexible magnesian limestone, may be used; so, also, may dry and sound cork, but these allow the diffusion to go on very slowly; their porosity being inferior to that of stucco, they are all surpassed by it. The preferred method is to close about one-fifth of an inch at one end of a glass tube half an inch in diameter and from six to twelve inches long, with such work. When dry, such a tube being filled with hydrogen over mercury, the diffusion commences instantly, and in twenty minutes the whole of the hydrogen escapes. The plaster must be kept dry; therefore, in experimenting over water, the air must be removed by a

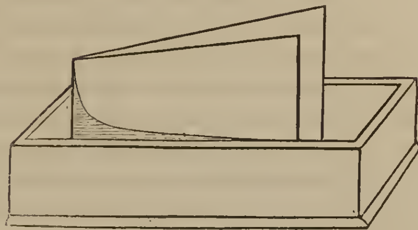
syphon before introducing the gas. The appearance of the water rising in the tube from which the hydrogen is diffused, is striking; but, on experimentally determining the proportion between the gas escaping and the air entering, it is necessary to keep the pressure uniform by preserving the water at the same level within and without the tube. On the principles of pneumatics, the velocities with which bodies rush into a vacuum should correspond with their diffusion volumes. This law has been considered as confirming the opinion that gases act as vacua to each other. To this view, however, it has been objected that "1. It is supposed, on that law, that, when a cubic foot of hydrogen gas is allowed to communicate with a cubic foot of air, the hydrogen expands into the space occupied by the air, as it would do into a vacuum, and becomes two cubic feet of hydrogen of half density. The air, on the other hand, expands in the same manner into the space occupied by the hydrogen, so as to become two cubic feet of air of half density. Now of gases actually expanded through each other in this manner, cold should be produced, and the temperature of the mixed gases should fall 40 or 45 degrees. But not the slightest change of temperature occurs in diffusion, however rapidly the process is conducted. 2. Although the ultimate result of diffusion is always in conformity with Dalton's law, yet the diffusive process takes place in different gases with very different degrees of rapidity. Thus the external air penetrates into a diffusion tube with velocities denoted by the following numbers, 1277, 623, 302, according as the diffusion tube is filled with hydrogen, with carbonic acid, or with chlorine gas. Now, if the air were rushing into a vacuum in all these cases, why should it not enter it with the same velocity? Something more, therefore, must be assumed than that gases are vacua to each other, in order to explain the whole phenomena observed in diffusion."

34. *Capillarity* is a general term applied to certain phenomena of both attraction and repulsion; we shall hereafter treat of the latter, for the present confining our attention to

Capillary attraction: A number of the phenomena of molecular action are arranged together under this head: of these the ascent of liquids in capillary tubes is the most conspicuous, and consequently confers a name upon the one cause of the whole class. When a body is plunged vertically partly into a liquid capable of adhering to it, the liquid rises to an indefinite height on the side of the body, covering it with a film whose thickness diminishes as it rises, its surface being concave. This film may be considered as made up of a succession of films, that nearest the body being highest, and the other progressively less high, the first being supported by adhesion to the solid, and the others by cohesion. To better understand the mode of ascent of the liquid on the side of the solid, the surface of the latter may be considered as divided into a number of small portions parallel to the liquid surface, the lower of which attracts a portion of the fluid, this being thus brought within the sphere of attraction by the second, rises to it, and its place is supplied by another portion; in like manner each portion of the liquid is attracted and elevated by the solid surface above it. The ascent stops at the point where the weight of the accumulated liquid is equal to the elevating force. The result is entirely independent of the thickness of the solid body, whose surface alone acts, the force being exerted only at insensible distances. If two plates of glass be partially immersed in water, or other liquid capable of moistening them, near each other with their surfaces parallel, they will co-operate, and the liquid will rise to heights inversely as the distances; if they be placed with one vertical edge of each in contact, and thence opening at an acute angle (Fig. 20), the liquid will rise between them, the surface of the raised part being curved; at any

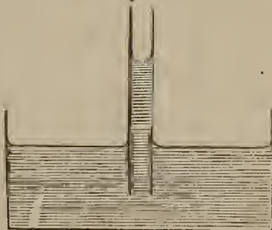
two points of the curve, the height will be inversely as the distances of the plates.

Fig. 20.



An open glass tube being put into a similar situation, the liquid will rise (Fig. 21) within it to twice the height it would attain between two plates separated by an interval equal to the internal diameter of the tube. The surface of the elevated liquid is a concave hemisphere, whose diameter is that of the tube.

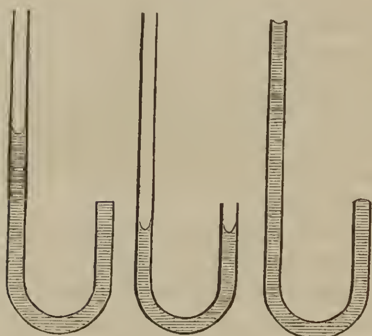
Fig. 21.



It is thought that the liquid molecules tend to preserve a level surface, and the external force having disturbed their equilibrium, they are thrown into a state of tension which causes their ascent. This tension is illustrated by a soap-bubble retaining its form while the tube upon which it is blown is kept closed; but upon opening it the bubble contracts with force quite manifest if the escaping air be directed against the skin or the flame of a candle. The tube being carefully withdrawn a column of liquid is retained whose height is always greater than when immersed, the height depending upon the size of the drop remaining on the extremity; the walls of the tube being thick the drop is large and the height less, but if they be thin the drop is small and the height greater. The tube having the form of a syphon, a liquid poured in will stand at the same height in both branches, while it does not reach the end of the short

one, when it has reached so far more may be poured into the longer branch to a constantly increasing excess of height, the concavity of the surface in the short branch proportionally diminishing till it becomes level, when the excess of the column in the long branch is equal to what a straight tube of the same diameter would elevate. Still more liquid can be poured into the long branch till the excess of the column is doubled, when that .in the short one will have a convex hemispherical surface; if more be added the liquid will flow from the short branch and the column in the long one will fall to an extent dependent upon the size of the resulting drop. (Fig. 22.) The heights to which liquids will be raised by capillarity vary greatly with different liquids; but are constant with each, and do not appear to bear any relation to the densities, nor to depend on the nature of the tube, it being necessary only that it be moistened. In similar tubes the height of water being represented as 3·4, the numbers denoting those of solution of ammonia will be 3·6, of anhydrous alcohol 1·8, and of sulphuric acid 1·3. In a tube 0·05 in diameter, water (s. g. 1,000) is elevated 0·92 inch, alcohol (s. g. 8195) 0.36, and oil of turpentine (s. g. 0·8695) 0·39.

Fig. 22.



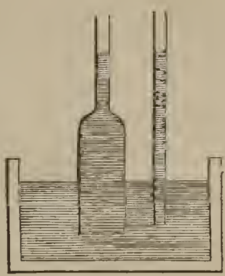
35. If the tube be conical, and but a section of it be filled with an adhering liquid (Fig. 23), this will have two concave surfaces and the attraction of the glass, or the tension of the liquid, at those surfaces being inversely to the radius of the

curve, the liquid will pass to the narrower part of the tube.

Fig. 23.

For the same reason, if the tube be composed of two parts, one much smaller than the other, the height of the column sustained by it will depend upon the end which is uppermost being the same as if the tube were throughout of the same diameter as that end (Fig. 24): so a vessel of any shape having its upper part drawn into a capillary tube will sustain a column of water as high as the tube itself would. In an annular space of any thickness, the elevation is the same as in a tube of a diameter double that thickness: thus, if a rod of glass 0·36 of an inch in diameter be so fixed within a tube whose internal diameter is 0·4 of an inch, that their axes shall coincide, there will be between them an annular space 0·02 of an inch in thickness, and in this space liquid will be elevated as high as in a tube the diameter of whose bore is 0·04 of an inch. If in this experiment a tube be substituted for the rod, both tubes will act separately: thus, if the diameter of the bore of the inner tube be double the thickness of the annular space, the liquid will stand at the same level in both; if it be less, its column will be higher; if it be larger, its column will not be so high. If the outer tube be much shorter than the inner and be closed at one end, the same changes can be produced as with the syphon (§ 34, Fig. 25). Two glass plates meeting by an edge of each at the small angle and these edges being placed horizontally, a drop of water

Fig. 24.



introduced so as to touch them both, will pass rapidly towards the edges in contact; if the upper plate be retained in the horizontal position and the angle be increased while the drop is moving, its motion will be retarded by the force of gravity, and may be entirely overcome. (Fig. 26.) The influence of the solid extends to a considerable distance along the surface of the liquid: thus, a light ball of a matter capable of being moistened by water floating on its surface, will move even to the distance of an inch to the side of the vessel containing them. And if two such balls be placed at the distance of an inch apart on the surface of water in a larger vessel, each will attract the water at half that distance, and the tension thus developed at its surface, will cause the balls to approach each other. (Fig. 27.) A space completely filled cannot exert any capillary action; hence, to whatever height in a tube a liquid may be raised by capillary attraction, it never runs over the top. Cotton-wick which is composed of a great number of vegetable hairs united together with minute spaces between them, in which various liquids, *e.g.* oil, water, etc., will rise: by means of it a vessel may be emptied; but it is not by capillarity, but by gravity, that the liquid flows from the lower end; for the escape may be immediately stopped by bringing the cotton to a horizontal position. The influence

Fig. 25.

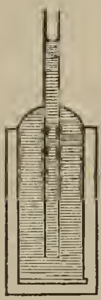


Fig. 26.

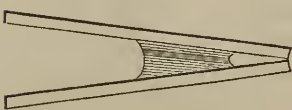


Fig. 27.

of capillary attraction is remarkably exhibited in its prevention of evaporation: thus, tubes filled with water as entirely as they can be by this force, have been exposed for months to the action of the sun without any appreciable loss of the liquid.

36. *Imbibition* is an example of adhesion and of capillarity strictly so called; for water being brought into contact with sugar, sand, sawdust, ashes, sponge, or blotting paper, it adheres, and they become moist, and having a multitude of minute cavities, ramifying more or less tortuously, quickly draw up the liquid, and become saturated. So also organic tissues, as cartilage and tendon when dried, if plunged into water soon imbibe a portion, and regain all the physical properties they possessed during life. Water by capillary force passes into a strainer, *e.g.* filtering paper, and by cohesion collects below into drops, and by gravity falls away. Solid particles being suspended in a liquid will rest upon a filter, while the liquid soaks into its substance. Drops of colored liquid, like chocolate or ink, falling upon cloth or other similar texture, the liquid is attracted from the more solid part, leaving them as a dark spot, surrounded by a zone less deeply colored. A similar effect follows the effusion of blood into the cellular tissue under the skin, the serum being carried to the margin. The subject of imbibition was investigated experimentally a few years ago in Tuscany in the following manner. Six glass tubes about four-fifths of an inch in diameter, each closed at one end by a cloth tied round it, were filled with sand previously passed through a very fine sieve, and dried by a water bath; agitation being carefully avoided, so that it might be equally compressed throughout. The closed ends were all at the same time plunged one-fifth of an inch deep into six different liquids, all at 73° F. The imbibition commenced immediately, rapidly at first, but becoming progressively slower for ten hours, at which period it ceased. The liquid

was replaced occasionally, so as to keep the pressure uniform in all the vessels. It was found that different fluids were imbibed in very different proportions, *e.g.* solutions of gum, boiled starch, and oil, scarcely at all; concentrated saline solutions and all liquids holding very minute solid particles in suspension very slightly. The last underwent a kind of filtration. Among the following articles the saline solutions were all of one density, viz. 10 Baumé; white of eggs mixed with an equal quantity of water ascended 35 millimetres; milk, 55; solution of chloride of sodium, 58; distilled water, 60; solution of the carbonate of ammonia, 62; serum, 70; solution of sulphate of copper, 75; solution of carbonate of soda, 85. It was found that as in capillary tubes, so in tubes filled with sand or pounded glass, water is raised higher than alcohol; in sawdust, on the contrary, it was not so much raised, as is here represented.

	In Sand.	In Pounded Glass.	In Sawdust.
Alcohol rose	85 mm.	175 mm.	125 mm.
Water rose	175 mm.	182 mm.	60 mm.

Two tubes, one containing twice as much pounded glass as the other, were placed in water; in the former the water was raised 170 mm., in the latter but 107 mm.; the cause of this difference is somewhat obscure, but it was attributed to the greater extent of solid surface and much smaller diameter of the capillary cavities in the former. Temperature was found to influence the process: two tubes prepared with sand were plunged equally into separate portions of water, one being at 131° F., the other at 59° F., after 70 seconds the elevation in the former was 10 mm., in the latter 6 mm.; after eleven minutes, in the former it was 175 mm., in the latter 12 mm. It appeared to proceed equally well in air, dry or saturated with moisture. Imbibition by sand, ashes, and sawdust, was found to go on as well under the exhausted receiver of an air pump as in the open air;

though it progresses more rapidly *in vacuo* during the first few seconds, at the end of ten minutes no difference was observed. It might appear that a column of light powder, *e.g.* sand, ashes, &c., would become saturated throughout by imbibing a liquid into which its lower end is immersed; but this expectation is not realized by experiment; the imbibition becoming progressively slower till it reaches a point, certain for each material, when it ceases entirely. This occurring at the same place in dry air or air saturated with moisture, cannot be caused by evaporation from the upper surface. It has been attributed to little canals reaching along the length of the column, and by their capillary action aiding the adhesion of the liquid to the surface of the solid. This explanation appearing to represent a force limiting its own exercise is not satisfactory; it has been with more plausibility referred to the counterbalancing agency of gravity. More or less heat and electricity have been observed to be disengaged during capillary action; in this respect it resembles chemical attraction. Moreover, salt water flowing through a long tube filled with sand, has been observed to lose its salt; but this, according to the observations in Tuscany, occurs only at first, the fluid after a short time passing out as dense as when introduced; and solution of carbonate of soda was found to be increased in density by flowing through ten feet of sand.

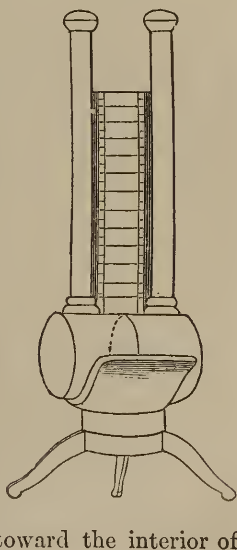
37. *Osmose* is the transmission of liquids into each other through the pores of an interposed medium, which ordinarily offers more resistance to the passage of one of the liquids than of the other. The phenomena can be exhibited in their greatest simplicity with the instrument called "endosmometer," which consists of a glass tube, one of whose ends is closed by a piece of bladder, and placed with its closed end in an outer vessel. *Endosmose* (from ενδον and ωσμος) is the passage of the outer liquid into the interior. *Exosmose* (from εξω and ωσμος) is the outflowing of the inner liquid.

Endosmose.—If a solution of sugar or gum be poured into the instrument, and the closed end be placed in pure water, the water will continually enter through the membrane, notwithstanding the pressure of the solution above, and the tube will thus be filled even to overflowing. At the same time some, but less, of the solution will pass out and mingle with the water. Membranes act thus, even till at the point of putrefaction; but as soon as that commences the raised liquid descends and filtrates. Layers of slate, and still better baked clay, also have this property. Endosmosis is greatly influenced by the nature of the fluids. The velocity of the current is in direct proportion to the excess of density of the liquid within over that without, excepting alcohol, which produces endosmosis of water placed externally. Through a membrane 4 millimetres thick upon a tube 2 mm. in diameter divided into spaces each 2 mm. long, in an hour and a half, into a solution of sugar with a density of 1·083, a column of water has been found to rise 19½ divisions, into a solution with a density of 1·145 to rise 34, and into a third solution with a density of 1·228 to 53. It appears that, of all organic substances soluble in water, albumen produces endosmose with the greatest force; for the following solutions, of the same densities, being separated from water by a bladder, solution of gelatine drawing in 3 measures, solution of gum drawing 5·17, that of sugar 11, and that of albumen 12. The endosmose of water is caused energetically by all animal fluids, except those usually found in the large intestines: the cause of these not producing it is probably the sulphuretted hydrogen which they contain; that gas completely preventing its manifestation in a membrane with which it has been but a short time in contact. The slightest trace of sulphuretted hydrogen or of sulphuric acid modifies its production, a property not possessed by hydrochloric nor nitric acid. The passage is facilitated by an increase of tempera-

ture. Endosmose occurs from water to a solution of hydrochloric acid with a density of 1·02; but if the density be 1·015 the current is in the contrary direction; if acid with this density be used at a temperature above 68° F. the current is again reversed.

That the above velocities are to be considered invariable only when through bladder, is evident from experiments with different kinds of membranes. In each experiment two endosmometers were used, each 3 mm. in diameter, prepared with the same kind of membrane, which was attached to the one with its outside and to the other with its inside towards the interior of the tube, both being immersed into the same vessel. Sometimes an instrument has been used which is essentially a cylinder separated into two parts by the membrane, each communicating with a separate tube. (Fig. 28.) Besides spring water, which was generally exterior to the tube, the following liquids, always of the densities specified, have been used: sugar water, 19° Baumé; solution of white of eggs, 4°; solution of gum arabic, 5°; and alcohol, 34°. The experiments were continued two hours between the temperatures of 53·6 and 59° F. With the external surface of torpedo skin toward the interior of the tube the column of solution of gum was raised 30 mm., of syrup 30 to 80, of solution of albumen 26; with its internal surface toward the interior the column of gum solution rose 6 to 18, of syrup not more than 2, of solution of albumen 13. With the external surface of the skin of a frog toward the interior of

Fig. 28.



the tube the column of solution of gum rose 32, of syrup 36, of solution of albumen 24; with the position of the skin reversed the gum water rose 16, the syrup 24, and the solution of albumen 12. With the external surface of the skin of an eel toward the interior of the tube the solution of gum rose 20, the syrup 30, and the solution of albumen 8; with the skin in the opposite position the solution of gum ascended 17, the syrup 20, and the solution of albumen 4. Unlike the skins of the torpedo and the frog, the difference with the two sides of the eel-skin did not in the experiment upon syrup appear for some time; while in those upon solution of gum or albumen, it, as with the other skins, appeared immediately. The eel-skin having been detached from the animal two or three days, the difference of the height of the column in the two tubes was not seen. Freshness did not appear so essential in the frog or torpedo-skin. With these skins the current, as with the bladder, was always from water to alcohol. It was always influenced by the disposition of the membrane; but this was different in different skins. Through the frog-skin the current was more rapid from the external to the internal surface, the rise in such circumstances being 20, 24 and 40 mm., while in the contrary condition it was but 4, 12 and 20; but with eel-skin the current was much more rapid when from the internal to the external side, 20 mm. passing so while only 10 passed from the external to the internal; the difference was the same with the torpedo-skin as with the eel-skin, 50 mm. passing from the internal to the external side, while but 20 passed from the external to the internal. With the torpedo-skin, if it was recently prepared, the currents were as above stated; but after it continued an hour the current from the external to the internal side diminished, and ultimately ceased entirely, while the contrary current remained constant. These singularities have been attributed to chemical change effected in the

skin by the alcohol. The intensity of the endosmose was diminished but irregularly through eel and frog-skin, and with neither was the direction of the current changed.

The table here quoted exhibits the intensity of the endosmose of spring water into each of the liquids through the different skins:

	Solution of sugar. Mil.	Solution of albumen. Mil.	Solution of gum. Mil.	Alcohol. Mil.
Skin of torpedo, . . .	100	30	120	35
Skin of frog, ...	25	15	22	80
Skin of eel, ...	15	8	6	55

38. The mucous membranes of the stomach of the lamb, cat, and dog, and of the gizzard of the fowl, each carefully detached from the muscular coat, have been subjected to experiment. The endosmose of water into solution of sugar was greater from the external to the internal side through all except that of the lamb, in which it was the reverse; in the gizzard the difference was slight. Water passed into solution of white of eggs more rapidly from the external to the internal surface of the membrane of the lamb: through that of the fowl it passed equally fast whichever side was in contact with the solution, except in one experiment. The endosmosis of water to gum water was nearly equal either way; if there be any difference it is greater when the inner surface is towards the gum water. The endosmosis of water and alcohol was most active from the internal to the external surface; the current through the gizzard was always to the water—through the others always to the alcohol. With the mucous membrane of the bladder of the ox, separated from the muscular fibres, in a fresh condition, the following results were obtained: With syrup used within the instrument the ascent was more rapid when the internal surface was uppermost. With gum arabic solution as the inner liquid the column at first descended, but afterwards ascended; the height which it

attained was always greater when the external surface was uppermost. With alcohol the current was from the water: the influence of the surface was not decided. Drying or putrefaction destroyed nearly or entirely the influence of the surfaces. By soaking the membrane to which muscular fibres adhered, they became distended, and thus were restored to a condition similar to that of those in a fresh bladder: in either case the fibres interfered with the passage of the water. The phenomena of endosmose through organized tissues not presenting the uniformity observed in purely physical phenomena must be owing to their anatomico-physiological state. From the experiments here considered the following general conclusions have been deduced.

"1st. The intermediate membrane exerts a very active part in the velocity of the endosmosic current, as well as in its direction. 2d. There is, in general, with each membrane, a certain position in which endosmose is most active. The cases are very rare in which, with a fresh membrane, the endosmose is the same, whatever be its disposition with regard to the two fluids. 3d. The direction most favorable to endosmose through skins, is generally from the internal to the external surface, with the exception of that of a frog, through which the endosmose between water and alcohol takes place more vigorously from the external to the internal surface. 4th. The direction most favorable to endosmose through the stomach and urinary bladders is much more variable than through skin, according to the different fluids. 5th. The phenomenon of endosmose is closely connected with the physiological state of the membranes. 6th. With membranes dried or altered by putrefaction, there is either no endosmose, or if there be any, there is no difference in the different positions of the skin."

39. *Exosmose* is the flowing out of the inner liquid. It

had been supposed that this occurred in all cases, and that the rising of the fluid within the tube was caused by the inner current exceeding the outer. To determine this point the Tuscan experimenters employed the skins of frogs and eels, and for the denser fluid solution of salt or sugar. They used two instruments, one with the inner surface, and the other with the outer towards the interior of the tube. Into each they introduced an equal quantity of the solution of salt (or of sugar) in water, and placed them in separate glass vessels, each containing a quantity of distilled water equal in bulk to the solution. After two hours, each separate portion of liquid was measured. If the difference in the height of the columns, in the two cases, depended upon difference of strength in the inward and outward currents, then that column which had increased most in height should have been most reduced in density. But they observed that in the endosmometer in which there was the greater rise there was less change of density in the inner fluid; and that into its vessel containing the distilled water there had been exosmosed less salt water than into the other. They therefore concluded that the endosmose was equal in the two, and that the difference in height depended upon a greater quantity of salt water being exosmosed from that in which the column had ascended the less.

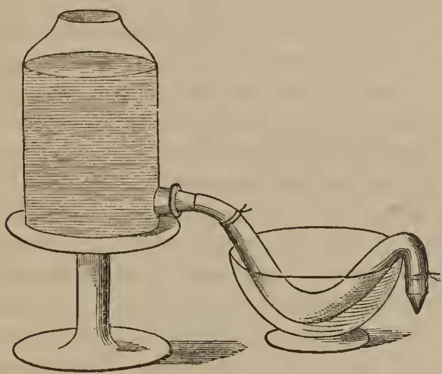
Though this subject, especially as it regards the comparison between different classes of animals, particularly the carnivorous and herbivorous, is far from being exhausted; yet the above results show the great importance of the action of the interposed membrane, the dependence of its action upon its physiological condition, and the intimate connexion between endosmosis and the functions of organic matters. The exosmosis of albumen, gum, and sugar, is most active from the inner to the outer surface of skins, the direction in which the copious secretions of mucus pass through the skins of eels, frogs, &c.; the endosmose of

water is but slight in the contrary direction; as these animals absorb but little water through their skins. Alcohol is the only fluid which acts in a contrary manner: having no analogy with any animal fluid its action cannot bear upon a question of physiology. The currents through the mucous coats of stomachs not being so uniform as through skins accords with the fact that in different animals, *e.g.* ruminant and carnivorous, the functions of digestion and absorption of nourishment are very much diversified. Microscopic observers have ascertained that, at a certain period of the formation of all vegetable and animal tissues, and of fluids generated by changes in living organized matter, they contain microscopic corpuscules called "cellular or elementary." These corpuscules are of a spherical form, and composed of a very thin membrane inclosing a liquid, and having on their inner side a small organized body called "cytoblast, or nucleus." The corpuscules originate in a liquid called "cytoblastema," and end in being compressed together, the cytoblastema or intercellular liquid becoming denser and always being the medium of union. The life of these cells forms the most essential requisite to the preservation and growth of living tissues: and as they contain one fluid and are surrounded by another, it is highly probable that endosmose is constantly taking place through the membranous coat. Thus, the ovules are nourished in the ovaries of mammiferous animals; and thus, the sacs containing the germs of cephalopodous mollusca open when they come in contact with water. Certain purgative substances causing an increased quantity of albumen to be evacuated, it was conjectured that their action might be by causing endosmosis; and it has been accordingly ascertained that solutions of sulphate of soda and of chloride of sodium and seidlitz water produce endosmose of serum through animal tissues. The opinion has been further sustained by the observations that endosmose is much more

rapid when one of the fluids is in constant motion ; and that hydrochlorate of morphia added to these saline solutions diminishes the endosmose of serum, and finally reverses the current. Hence it has been asked : " How can this fact be entirely overlooked in explaining the action of morphine and preparations of opium as remedies for diarrhœa, and the constipation which they produce ?"

If a considerable portion of a large vein be fixed by one extremity to a tube communicating with the bottom of a glass-jar filled with water and by the other to a closed stop-cock ; and if a part of the vein be immersed in water acidulated with hydrochloric or sulphuric acid : after some time

Fig. 29.



the acid will be detected in the jar : if instead of waiting, the water be allowed to flow through the vein, the acid can be detected therein some time before it can be in the jar. If the experiment be modified by placing the acidulated water in the jar and vein, and water colored with tincture of litmus in the other vessel, this water and the acid will both be found to pass through the coat of the vein with a rapidity proportional to that of the current

from the jar through the calibre of the vein. The same results are obtained if an artery or a tube of clay, pasteboard or wood be substituted for the vein. Friction on the skin and the peristaltic action of the intestines facilitate absorption of substances applied to them, by expediting the movement of the liquids in their vessels. Exhalation is effected by a similar mechanism and is governed by the same laws. If a liquid be capable of being imbibed by the vessel containing it, a quantity proportional to the facility with which it is imbibed is constantly exhaled. The more humid the vessel is externally, the more rapidly does the internal liquid escape. Cutaneous transpiration is more rapid as the air is drier, being in some cases ten times greater than in others: and like simple imbibition it is facilitated by elevation of temperature, it is doubled in passing from thirty-two to sixty-six; it is also increased by agitation of the air surrounding the animal. When the arteries and veins are injected with a solution of gelatine in which fine vermilion powder is diffused, for the preparation of anatomical specimens, the solution passing through the coat becomes colorless. So in living animals the fluids imbibed on one side and exhaled on the other by a membrane are not identical. Thus though there is much obscurity about the nature of secretion, there is not an entire want of foundation for the opinion of the ancients, that glands were mere filtering machines. The cause of the ascent of sap is yet unknown, though it is intimately connected with a process very similar to, if not identical with endosmose, taking place in roots; in like manner the proper juice descends from the leaves. A fruit, such as a peach, just enlarging contains a fluid denser than the sap, by endosmose the sap is attracted into the fruit which becomes more bulky and juicy, the more watery part being exhaled into the atmosphere, the more solid parts of the sap become changed into pulp. In the passage of gases through porous

substances like membranes a degree of endosmosis probably occurs; a bladder filled with water slightly charged with carbonic acid being introduced under a bell glass full of hydrogen, oxygen or nitrogen, a part of the carbonic acid will leave the water and its place be supplied by the outer gas. Air having been removed from the lungs of a lamb by suction, its place partially supplied by oxygen gas and the larynx closed, they being introduced into a receiver full of carbonic acid over water, become in a few seconds as much distended as the receiver will permit: and both gases were found to have penetrated the lungs, but a much greater quantity of carbonic acid than of oxygen. A lung being filled with carbonic acid and introduced into oxygen contracts, and the gases mix; but the oxygen entering is less than the escaping carbonic acid. A soap bubble full of hydrogen or air floating on carbonic acid gas expands and sinks, being penetrated by both gases, but by more of the acid than of the other gas. These differences are attributed to water absorbing more carbonic acid than hydrogen or oxygen. Frogs having their lungs emptied by pressing on their chests and abdomens and being then plunged some into hydrogen and others into nitrogen, these gases were absorbed, and into the nitrogen gas carbonic acid was evolved while into the hydrogen both nitrogen and carbonic acid were given off. In fishes there is an exchange of oxygen and carbonic acid between the water and blood through the gills: and the same exchange takes place through the lungs in breathing animals between their blood and the atmosphere.

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40. Respecting the nature of the osmotic force, the cause of these phenomena, different conjectures have been advanced.

I. By some it has been thought to be electrical.

II. Much has been referred to the chemical reactions of the two liquids: but the advocates of this opinion being inclined to the electrical view make no attempt at explanation of the action of the septum.

III. Experiment has led others to the conclusion that one surface of the septum is acid and the other basic, this state being connected with a progressive decomposition of its substance; and that an alteration thereof is a condition indispensable for manifestations of the osmotic force.

IV. The action has been supposed to commence in capillarity and to be completed by the mutual alterations of the liquids, the attraction of the solid for the liquid only effecting the occupation of the numerous small channels by one liquid in preference to the other and the continuance of the liquid threads: the action then being only between the liquid A actually absorbed and the liquid B attracting it with a force superior to that exercised between its own molecules, the motion may take place as well in one direction as in the other; as soon as the pores of the septum are charged with the liquid A and its passage towards B being considered in consequence of its less bulk, more rapid than that of B towards A, it follows that if the septum be charged with B the movement will be in the contrary direction. To this theory it has been objected that the elevation of liquids in capillary tubes is very slight in comparison with the height of columns supported by endosmose. The objectors, however, appear to have overlooked the circumstance that the heights of the liquids in ordinary capillary tubes depend on the nature of the liquid and not that of the tubes, as is the case of endosmose, and that in the latter case an essential condition is a fineness of pores unattainable in ordinary capillary tubes. There is, however, a serious defect in the theory; viz. that the election made by the solid between the liquids is left out of view.

V. It is thought that osmose, instead of being caused by any peculiar force, is the effect of affinity, in the widest sense of the term including capillarity; and that it is erroneous to attribute osmotic force to chemical decomposition of the membrane or to suppose the acid always to flow towards the base; indeed oxalic acid, which produces the greatest effects, is asserted to be a conservative agent; and with an alcoholic solution of alkali and a very dilute aqueous solution of acid the base is carried through animal membranes and porous clay impregnated with castor oil towards the acid.

Porous clay, though possessed of very minute pores, is in osmotic faculty inferior to liquids which are among the most excellent osmotic agents. Two liquids of different densities being placed in a test tube and separated by another liquid of intermediate density and capable of dissolving an appreciable quantity of only one of the other liquids, this one will pass through the intermediate into the other, *e. g.* chloroform being covered with water, and this by ether, the last will gradually pass to the chloroform till all disappears. The experiment may be modified so as to bring into action increase of pressure, which is ordinarily present in osmotic experiments: to effect this the intermediate layer must be fixed, this is accomplished by saturating a porous vessel with the intended liquid septum, when the apparatus is arranged with the liquid which more readily mixes with the intermediate placed in the outer vessel: the action is clearly indicated by the rise of the column in the tube. A porous vessel impregnated with castor oil and filled with water being placed in alcohol this will pass to the water; whereas in the absence of the oil the principal movement will be of the water towards the alcohol.

41. *Chemical Affinity.*—This term is employed to designate that form of attraction which causes particles of different natures to unite and produce compounds possessed of

properties different from those of either of its ingredients. This force was thus figuratively named from the idea of attachment or aversion existing between particles. It is also called "chemical attraction" and "attraction of composition," because it is the cause of the formation of compound bodies. By simple or elementary bodies chemists mean such as have never been separated into more than one possessed of different properties. Many which are now known to be compounds were long thought to be simple; and there are reasons for supposing some which are regarded as simple to be compound; yet, having never been analysed, they must for the present be classed with the elements. Of the four supposed elements of the ancients (fire, air, earth, and water), the last three are now known to be compounds, and the first does not exist.

Analysis is the separation of a compound into its elements. Synthesis is the union of two or more simple bodies into a compound. Analysis and synthesis are mutual proofs each of the accuracy of the other. If water and olive oil, water and mercury, or mercury and oil, be mixed together, on allowing them to rest they will be found to separate unchanged in any of their properties; they are, therefore, said to have no affinity for each other. But if oil be mixed with a solution of potash, they will unite and form a liquid soap. If sulphur and mercury be rubbed together, they will be changed into a black powder called "sulphuret of mercury." The oil is said to have an affinity for the solution of potash, and the sulphur for the mercury. In general simple bodies unite with simple, and compound bodies with compounds; but in some instances, especially in the products of organic actions, a compound is found to act the part of a simple body, in which case it is called a "compound radical." Chemical affinity is exerted only between the minutest particles of matter; here it is promoted by solution, mechanical division, trituration, or other mode

of intermixture, *e. g.* bi-carbonate of soda and tartaric acid may be mixed together without any reaction; but upon the addition of water an effervescence occurs indicating the decomposition of the former by the latter. When chloride of ammonium is triturated with lime, they are decomposed, ammonia is evolved, and readily distinguished by its odor. Chloride of calcium and water are at the same time formed.

42. Chemical affinity does not cause bodies to approach each other. Bodies do not act on each other chemically unless they be in apparent contact, as will be illustrated by the following experiment:—Put into a glass vessel a solution of salt of tartar, and introduce under it, by means of a dropping tube, some glauber salts dissolved in water, and under this a portion of oil of vitriol; by so doing we have three layers of fluid, that of sulphate of soda separating the other two; but by stirring them with a glass rod these two will be brought into contact, and act chemically, as will be indicated by a violent effervescence. Sulphur and copper in mass do not affect each other, but if both be in a state of fine powder, and they be rubbed together in a mortar, sulphuret of copper (a new substance) is formed, with disengagement of much heat. Whatever promotes the approximation of the particles of bodies, at the same time, promotes their union: thus, the union of solids, as already shown, is promoted by mechanical intermixture, that of solids to liquids or gases, and of liquids to gases, by their tendency to adhere; of gases to gases by their property of diffusion; and of liquids to liquids by a somewhat similar property. Chemical attraction is exerted with very different degrees of force: thus, phosphorus unites with oxygen at all ordinary temperatures, and with great violence if the temperature be elevated; while silver cannot be directly united with it at any temperature. Potassium combines with oxygen in whatever form it is presented to it, and they cannot be separated except at very

high temperatures, or by means of great electrical power; while chlorine and oxygen cannot be united directly, and when combined (as they can be in several proportions), by indirect means, they are retained by so feeble an affinity as to be separated by a slight elevation of temperature, some of their compounds being decomposed even by the slightest agitation. The smallest quantity of any two acids necessary to form the simplest compound with a fixed quantity of any base having been ascertained, and the quantity of any other base necessary to form such a compound with either of the acids being then determined, the same quantity of this second base will be necessary to unite in the same way with the other acid, *e.g.* 40 parts by weight of sulphuric acid unite with 48 of potash, and 71 of phosphoric acid unite in the same manner with the same quantity of potash. The quantity of water present is left out of view. 31 parts of soda unite with 40 of sulphuric acid and with 72 of phosphoric acid; 48 of potash is therefore said to be equivalent to 31 of soda, and 40 of sulphuric acid to 72 of phosphoric acid; or more generally, the numbers are called the equivalents of the substances to which they are respectively attached. The equivalent of a compound is always the sum of those of its elements. By the old chemists solution was considered an instance of chemical action; but it is rather one of adhesion, a subject which, until recently, has received very little attention. Chemical action differs from solution, in that it occurs with more force as the properties of the bodies are more opposed: thus, acids unite more readily with oxides and alkalies; and in chemical compounds the constituents are always united in definite proportions.

43. Chemical combination is attended by a change in the properties of the substances uniting; some of the properties of one or both of the ingredients are lost, and others entirely new appear in the compound formed. Sulphuric

acid is a caustic, oily fluid, and reddens vegetable blue colors; and potash a white amorphous, caustic solid, and changes vegetable blue colors to green; by their union is formed the common vitriolated tartar, which is destitute of causticity, and has no effect on vegetable colors, but has a regular crystalline figure. The older chemists believed that the properties of compounds were the intermediates of those of their ingredients, but such examples as this, of which many might be adduced, show this to be a mistake. We can form no opinion of what will be the properties of a compound by knowing the nature of its component parts. When opposite properties disappear the combining bodies are said to neutralize each other, and the exact point at which this takes place is called the point of neutralization. A change of temperature usually attends chemical action; sometimes it is elevated, as in ordinary fires and fermentation. The mixture of water with oil of vitriol is attended by a considerable increase of heat. Sometimes there is a production of cold, *e.g.* powdered crystallized chloride of calcium and snow produce cold enough to freeze mercury. Chemical action is also sometimes attended by a change of color. If a portion of mercury (a silvery-colored metal) be agitated in contact with air, it is changed to a black powder; if heated with access of air it is changed to a red powder, owing to its combining with one of the constituents of the atmosphere. Mercury, by combining with iodine, a bluish black crystalline matter, forms iodide of mercury, crystals of a scarlet color. If an infusion of oak bark be added to a transparent liquid containing iron, a black color will be produced. A change of form or density is frequently effected by chemical action. A liquid or gas is sometimes produced by the reciprocal action of two solids; a solid or gas by that of two liquids, and a solid or liquid by that of two gases. The solid amalgam of lead and that of bismuth by combining form a liquid. If quick-

lime be heated in contact with chloride of ammonium a gas is evolved. Phosphorus and sulphur heated together in certain proportions unite and form a liquid. Sulphuric acid mixed with one-sixth or one-fifth its weight of alcohol, and heated, yields olefiant, carbonic acid, and sulphurous acid gases, and vapor of ether. Oxygen and hydrogen gases exploded together produce water. Euchlorine gas and twice its weight of hydrogen gas, detonated together, become liquid hydrochloric acid. Ammoniacal and hydrochloric acid gases, immediately upon coming into contact, unite and form a solid chloride of ammonium. Two volumes of binoxide of nitrogen and one of oxygen unite and are condensed into one of hyponitric acid. Ammonia has, by analysis, been found to be composed of one volume of nitrogen and three of hydrogen condensed into two volumes.

If one substance be brought into contact with two others for which it has unequal affinities, it will unite with the one for which its affinity is the greater to the exclusion of the other; the first substance has been considered as making a selection between the other two; and it is therefore said to exercise an elective affinity or attraction; thus nitric acid will unite with lime in preference to magnesia: and water attracts alcohol more strongly than it does chloride of magnesium. If a substance in combination with another be brought into contact with a third for which it has a greater affinity than it has for the one with which it is combined, it will leave it and combine with the third. If to the combination of olive oil and solution of potash mentioned above, be added a portion of sulphuric acid, it will unite with the potash and the oil will be separated. This affords an example of what is called "simple decomposition;" it is owing to the potash having a greater affinity for the sulphuric acid than it has for the olive oil. Iodine decomposes sulphurated hydrogen forming hydriodic acid and disengaging the sulphur: bromine in a like manner takes hydro-

gen from hydriodic acid and forms hydrobromic acid; and chlorine liberates bromine from hydrogen and forms hydrochloric acid. The order of affinity of these elements for hydrogen appears to be chlorine, bromine, iodine, sulphur. The order of precipitation of metals by others from the solutions of their salt, was supposed to indicate the strength of their affinities for oxygen and the particular acid: *e.g.* mercury decomposes nitrate of silver precipitating the silver; in like manner copper precipitating mercury and silver from their nitrates, and zinc precipitating all of them, it has been inferred that zinc has a stronger affinity for oxygen and nitric acid than either of the other metals, copper a stronger affinity than mercury or silver, and mercury than silver. Bodies have been arranged in tables expressing the order of their decomposition, which are called "tables of elective affinity."

Sulphuric Acid,
Baryta,
Strontia,
Potash,
Soda,
Lime,
Magnesia,
Ammonia.

The affinities of bases for an acid are expressed by drawing a line under the name of the acid and writing under it the name of the base whose affinity for the acid is the strongest, and under it that of the one having the next strongest affinity, &c. Thus, according to the accompanying table, magnesia will take sulphuric acid from ammonia, and lime will take it from both ammonia and magnesia, &c. These, if correctly constructed, express accurately the order of decomposition in one set of circumstances; but do not express the independent force of affinity, this being very much modified by contingencies.

44. The causes modifying the action of affinity are as follow:

I. *Alteration of Temperature.*—Mercury, if long exposed to the air at a high temperature, becomes changed into bright red crystals by combining with oxygen, a part of the air; if the temperature be raised still higher the mercury and oxygen separate. It is supposed that this may, in part, be owing to the mercury tending to assume the state of vapor. But this cannot be the reason, because oxygen exists as a gas when free, even at ordinary temperatures.

45. II. *Cohesion.*—When in full action this force interferes with chemical affinity, *e.g.* if carbonate of lime in the form of a lump of marble be thrown into sulphuric acid, the reaction is very slight, but if it be reduced to fine powder, and then added to the acid, there will be a rapid evolution of carbonic acid gas. Two solid bodies rarely react. A mass of lead becomes speedily tarnished by exposure to air; but the crust of oxide formed protecting the inner part, and the conducting power of the mass preventing the elevation of temperature from the oxidation of the surface, the process stops, only the surface being covered by a thin layer of oxide; but if lead be reduced to a powder and agitated with water containing the usual amount of air, it is speedily converted into a white oxide, in the state of extreme division, to which it is brought by calcining the tartrate in a glass tube, it takes fire, even in cold air combining with the oxygen of the air. Iron in mass scarcely rusts in dry air; but by reducing the sesquioxide of iron by means of hydrogen gas, at a low red heat, the iron is brought to the state of an extremely fine powder; this, upon coming into contact with the atmosphere at ordinary temperatures, immediately takes fire. In such cases too great a surface is acted upon at once to allow the caloric evolved to be conducted away before the metal is burnt. Cohesion scarcely existing in liquids the action be-

tween two bodies is greatly facilitated by one or both being in a liquid state. Insolubility is very much owing to the prevalence of cohesion, and accordingly interferes with affinity. A large proportion of chemical reactions occur between bodies in solution and are affected by the relations of them and their product to the solvent; carbonate of potash dissolved in water is decomposed by acetic acid, the acetate being soluble in water; it is also soluble in alcohol, while carbonate of potash is not soluble therein; if, therefore, a stream of carbonic acid gas be passed into a solution of acetate of potash in alcohol the carbonate of potash is formed and immediately precipitated.

46. III. *Elasticity.*—If the affinity between two gases be great they will, from their property of diffusion, react without interruption, until one or both is entirely neutralized. If hydrochloric acid and ammoniacal gases be admitted into a vessel containing atmospheric air their combination proceeds, forming chloride of ammonium, until the whole of that which may be the smaller in quantity has united with an equal bulk of the other. The volatility of a body facilitates its disengagement from another more fixed, *e.g.* the commercial "carbonate of ammonia" is not uniform in composition, but, when fresh, approaches two equivalents of oxide of ammonium and three of carbonic acid; being exposed to the air it evolves ammonia and becomes bi-carbonate of ammonia. By a great heat sulphuric acid is driven off from oxide of iron which is fixed. Whatever retards volatilization, *e.g.* pressure, will prevent the decomposition in such cases. On the contrary, it is promoted by any cause which will expedite the escape of the volatile matter, *e.g.* an atmosphere of a different nature. An aqueous atmosphere favors the escape of nitric acid; accordingly nitrate of alumina and nitrate of iron lose a portion of their acid by the spontaneous evaporation of their solutions. Carbonate of lime may be heated to redness in a crucible with

but a very partial decomposition; because the small quantity of carbonic acid evolved remains in contact with it, and does not afford a suitable vehicle for the escape of more; while if there be a current of air passing through it the whole of the acid may be separated. The affinities of hydrogen and iron for oxygen appear to be nearly balanced; and steam affords a suitable atmosphere for the diffusion of hydrogen, as does hydrogen for that of steam; while each tends to repress the escape of its own kind. Hence if iron be heated red-hot in a porcelain tube, and steam be passed over it, the oxygen unites with the iron, and the hydrogen passes off as a gas; but if oxide of iron be heated to redness in the tube, and a stream of hydrogen gas be passed through it, the hydrogen separates the oxygen from the iron, and water is formed, which passes on as steam.

47. IV. *Nascent State.*—When a body is in the act of being liberated from combination it is in the most favorable condition for uniting with other bodies. In such circumstances some bodies enter into a combination which cannot be made to combine in any other manner, *e.g.* carbon and nitrogen, in the gaseous state, will never unite with hydrogen; but when they are simultaneously set free, as in the destruction by fire or by putrefaction of organic matter, they readily unite. Silicic acid is ordinarily insoluble, but when freshly disengaged from oxide of iron or an alkali it combines with water, forming a soluble hydrate.

48. V. *Substitution*, *i.e.* where one element takes the place of another in a compound, thus forming a new compound, the number of equivalents in which are the same as in the original, but part of them different in their nature, *e.g.* when hot iron acts upon water it takes the place of the hydrogen, which is set free, and forms oxide of iron. In many cases compounds are much more easily formed by substitution than by the direct union of their constituents; some can be obtained only in this way. Carbonic acid is

not absorbed by anhydrous lime, but readily by its hydrate, the water being displaced by the acid. Phosphoric acid forms three hydrates, containing one, two, and three equivalents of water. By substituting an equivalent of soda for one of water six different phosphates of soda may be formed from these three hydrates.

49. VI. *Disposing Affinity.*—This name is applied to a supposed cause modifying the exercise of affinity in a large class of remarkable actions, *e.g.* iron or zinc may be a long time in contact with water without undergoing any change; but if sulphuric acid be added, hydrogen is speedily evolved and sulphate of oxide of iron or sulphate of oxide of zinc is formed. The acid dissolves off the oxide as fast as it is formed: the water alone is decomposed. Why this decomposition proceeds more rapidly in the presence of the acid is not clear. It is generally said to be owing to the affinity of the acid for the oxide disposing the metal to act more promptly. Silver cannot at any temperature be directly united with oxygen; yet if ignited, in a finely divided state, in contact with a silicic acid and an alkali, it combines with oxygen, and silicate of silver is formed. Platinum has less affinity than even silver for oxygen, yet under the disposing influence of potash it unites with it; thus if platinum be heated in contact with hydrate of potash, hydrogen is evolved, and protoxide of platinum is formed, which, like an acid, combines with a portion of the potash to form a salt.

50. VII. *Quantity of Matter.*—When two elements can combine in different proportions they unite with the greatest force in that compound where the number of equivalents is smallest; *e.g.* binoxide of hydrogen is with difficulty preserved, while water requires considerable force to decompose it. When a compound of two substances is decomposed by a third, the process is most rapid at first; unless the one disengaged be removed immediately from

the sphere of action, its increased quantity appearing to compensate in part for its weaker affinity. It is, therefore, often necessary to add more of the third than is necessary to neutralize the one with which it is designed to unite.

51. VIII. *Gravity.*—Great difference in the specific gravities of bodies, tending to separate them, interferes with the action of affinity: thus in cases of solution the lower portion is generally more nearly saturated than the upper, unless they be agitated: and unless the same precaution be taken, the upper part of an alloy of metals having different specific gravities will contain less of the heavier metal than the lower part. By removing the newly formed compound out of the sphere of reaction, and thus allowing the nearer approach of the combining bodies, gravitation may aid affinity.

52. IX. *Mechanical Action.*—The influence of this cause is evinced by fulminating powders being exploded by a blow, and phosphorus inflamed by friction with chlorate of potash or alone. Oxygen and hydrogen unite with explosion if suddenly and violently compressed.

53. X. *Presence of a Solid.*—The mere presence of a solid will sometimes, without being itself changed, promote the union of two other bodies, one or both of them being gaseous, *e.g.* oxygen and hydrogen gases may be mixed in a glass vessel at any temperature short of redness without combining; but if a clear plate of platinum be introduced, even while the gases are cold, the portions of the gases in contact with it instantly unite: other portions then coming into contact with the metal enter into combination: the platinum becomes heated even to redness, but is otherwise unchanged, when the mixture will be kindled. Some other bodies, as metals, charcoal, and pounded glass, producing the same effect, favor the opinion that it depends on the adhesion of the gas to the solid; but the fact that only platinum and a few similar metals produce this same effect

without the aid of heat shows that the platinum acts in some other way. This conclusion is favored by the fact that if any carbonic oxide be present, it will prevent the union of the hydrogen and oxygen, until the whole of the carbonic oxide has united with an additional equivalent of oxygen; although when by itself it unites with oxygen much more slowly than hydrogen does.

54. XI. Catalysis (from κατα, downwards, and λυω, I unloose). This term has been proposed as the name of a modification of chemical affinity, by which a body causes the resolution of others, with which it is in contact, into new compounds without itself undergoing change. The existence of such a force has not been proved; but it has been inferred, and the above term is used as a convenient title under which to arrange a large number of facts not readily accounted for. By boiling a solution of starch ($C_{12} H_{10} O_{10}$) in water with an acid, the starch is made to unite with an equivalent of water and become gum ($C_{12} H_{11} O_{11}$): by continuing the action, three more equivalents of water are united with it, and they are converted into grape sugar ($C_{12} H_{14} O_{14}$),* the acid in neither case being altered. The same change is effected in the starch of germinating seeds by diastase, a substance existing in them in a small quantity, the gum and grape sugar formed being dissolved constitute the sap. In like manner in fermentation yeast converts sugar into carbonic acid (CO_2), and alcohol ($C_4 H_6 O_2$). Binoxide of hydrogen upon mere contact with various metals, *e.g.* manganese, silver, gold, and platinum, metallic oxides, *e.g.* oxide of silver and oxide of gold, or the organic matter, fibrine, evolves one-half of its oxygen: with the exception of a few oxides these substances do not combine with the disengaged oxygen; and some, *e.g.*

* These expressions denote the composition of three different matters, C. indicating carbon, H. hydrogen, and O. oxygen, and the figures the number of equivalents.

oxide of gold and oxide of silver, part with their own oxygen at the same time. Persulphuret of hydrogen is in like manner separated into sulphuretted hydrogen and sulphur by most of those bodies which decompose the binoxide of hydrogen. And spongy platinum, silver, oxide of silver, binoxide of manganese, and charcoal powder, acids and metallic salts, by mere contact decompose a solution of sulpho-nitrate of ammonia forming sulphate of oxide of ammonium and protoxide of nitrogen.

XII. Light, heat, electricity, and magnetism. Each of these influence chemical affinity; but can be more profitably discussed in treatises on the respective subjects.

55. *Double Elective Affinity and Double Decomposition.*—Two neutral salts may decompose each other; and in such cases the resulting compounds are always neutral, a consequence of the law of equivalents, *e.g.* solutions of nitrate of baryta and sulphate of potash being mixed, both salts are decomposed, and the neutral salts, sulphate of baryta and nitrate of potash, are formed: 54 parts of nitric acid, which neutralized 77 of baryta after decomposition, neutralize 48 of potash; and the 40 sulphuric acid which have neutralized 48 of potash, now neutralize 77 of baryta. Such decompositions are sometimes represented by a diagram; thus the decomposition of carbonate of ammonia by hydrochlorate of lime is exhibited.

Carbonic acid, Ammonia,
Hydrochloric acid, Lime.

Now each of the acids having an affinity for each of the bases, it has been supposed that the decompositions depended upon the affinities causing the decompositions surpassing those tending to preserve the original compounds: the former have been called "divellent affinities," and the latter "quiescent." In the above example the affinity of carbonic acid for ammonia, and that of hydro-

chloric acid for lime, are quiescent; and those of carbonic acid for lime, and hydrochloric acid for ammonia, are divellent. In these cases, there being two salts decomposed, and, as it were, two solutions of base made by the acids, the name "double elective affinity," or "complex affinity," has been applied to the causes, and "double decomposition" to the effect. In these reactions there is a double substitution. Although they occur usually between two binary compounds or two simple salts, they are by no means confined to them, but sometimes occur among more complicated bodies, *e.g.* double salts; and the union of bodies is thus effected, which can be in no other way, *e.g.* sulphate of soda and sulphate of zinc, if dissolved together, will always crystallize apart; but if strong solutions of bisulphate of soda and sulphate of zinc be mixed, a double sulphate of soda and zinc is formed and crystallizes: the reaction may be thus represented—

BEFORE DECOMPOSITION.	AFTER DECOMPOSITION.
2 *eq.* Sulphuric acid, 1 *eq.* soda, and 1 *eq.* water.	1 *eq.* Sulph. acid and 2 *eq.* water.
1 *eq.* Sulphuric acid, 1 *eq.* oxide of zinc, and 1 *eq.* water.	1 *eq.* Sulphate of zinc and 1 *eq.* sulphate of soda,

the 1 *eq.* of sulphuric acid being left in solution. A double sulphate of soda and lime can be formed only in a similar way, viz. by mixing solutions of sulphate of soda and acetate of lime; the sulphate of lime formed is precipitated and carries with it sulphate of soda.

56. *Complex Affinity*, like simple affinity, is modified by circumstances, *e.g.* if the above decomposition of carbonate of ammonia by hydrochlorate of lime was owing merely to the strength of affinities, the carbonate of lime should never be decomposed by hydrochlorate of ammonia; yet if they be mixed together and heated they are decomposed,

the carbonate of ammonia is formed and volatilized, leaving chloride of calcium, the volatility of the carbonate of ammonia favoring the decomposition. It is also modified by the insolubility of one of the compounds capable of being formed. It is a law without a known exception, that if an insoluble compound can be formed, decomposition will follow the mixing solutions of two salts. The decomposition of carbonate of soda by nitrate of lime results entirely from the insolubility of carbonate of lime. The affinities are so nearly balanced in cases of double decomposition that no great evolution of heat attends them. Precipitation does not invariably attend double decomposition; but such a result may be made apparent by a mere change of color. Sulphuric acid is disengaged from sulphate of copper by hydrochloric acid, and chlorine is disengaged from chloride of sodium by sulphuric acid. Upon mixing solutions of sulphate of copper and chloride of sodium, the blue color of the former is changed to green, denoting that the above substitution of ingredient has taken place. At an early period in the history of modern chemistry reflection upon the phenomena of double decomposition led to the conclusion that they are not owing to the difference in the forces of affinities, but depend entirely upon the attending circumstances; that if two acids are presented at the same time to one base, they unite with it in quantities proportional to their quantities; and that one comes into possession of the whole base only by reason of these modifying causes, *e.g.* upon mixing eight equivalents of nitrate of potash with eight of sulphuric acid, the salt is but partially decomposed, and the products are, 4 sulphate of potash, 4 nitrate of potash, 4 sulphuric acid, and 4 nitric acid. If now the 4 nitric acid be by any means, *e.g.* by heat, removed from the mixture, there is a further decomposition, the result being 6 sulphate of potash, 2 nitrate of potash, 2 sulphuric acid, and 2 nitric acid. The continued application

of the heat volatilizes the nitric acid as it becomes free, and the sulphuric acid is finally present in so great quantity as to take all the potash to itself. So, according to these views, in decompositions attended by precipitation, this precipitation leads to the total decomposition. By adding baryta to sulphate of soda, the acid is divided between the bases in proportion to their quantities; but the sulphate of baryta is precipitated, and any additional baryta acts upon the sulphate of soda, and so on until the whole of the sulphuric acid is separated from the baryta. It has been contested that this opinion is inconsistent with certain facts. 1. A solution of bibarate of soda is decomposed by sulphuric acid without any precipitation, which is proved by the different shade of redness communicated to litmus paper by the solution after the addition of the acid, and by sulphuric acid itself. 2. The tastes of fictitious mineral waters depend not only on the nature of the salts in them, but also on the order in which they are added. The more general opinion now is that in these waters the stronger acids are combined with the stronger bases. Recent researches, however, on a very extensive scale, rather favor the opinion that decompositions depend not upon the strength of affinities, but upon the attendant circumstances.

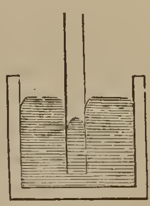
REPULSION.

57. Repulsion is the influence exerted by one body upon another, increasing the distance between them. Caloric is a frequent cause of this action. Electricity and magnetism likewise often produce this effect, *e.g.* two bodies free to move, and excited by the same kind of electricity, repel each other; and the north poles of two magnets repel each other, as do two south poles. It has been also supposed that all matter is endowed with this property, needing only favorable circumstances to admit its exhibition; that a film

of repulsion covers the surface of all bodies, and prevents their absolute contact, even when apparently touching, thus preventing the coherence of all bodies, which would interfere with all common operations of nature. The terms repulsion and repulsive force have been applied to the supposed power, causing this effect. The existence of such a force is a question, the absolute settlement of which is attended by great difficulties; yet it seems very doubtful whether there be any other film of repulsion than the calorific and luminiferous ether pervading all space. Some very important effects are attributed to repulsion, *e.g.* motion is said to be accelerated, retarded, or curved by repulsion. Motion accelerated by repulsion is said to be exemplified by the ball propelled by the explosion of gunpowder, which, in passing from the breech to the muzzle of a gun five or six feet long, acquires sufficient velocity to resist the action of gravitation during an ascent of a mile or more. That an ivory ball falling against a slab of marble does not stop at the moment of contact, is evident from this fact: if the surface upon which it falls be wet, a considerable space on both around the point of contact will be dry; the same effect following in vacuo shows that it is independent of the air passing out between the two surfaces, but is produced by the particles being compressed; while this compression progresses, the onward motion of the ball is retarded, and finally overcome so as to be reversed. Motion is curved by repulsion, it is said, in the following manner: if a ball of ivory fall upon a marble slab in an oblique direction, its motion is overcome and reversed, as already stated. The oblique direction is resultant of two forces: the propelling power which gives an onward motion, and gravitation which gives a downward direction; this last being overcome by the marble. The repulsion between the ball and marble imparts to the ball an upward motion, but its onward motion not being affected by the marble, the ball passes in the

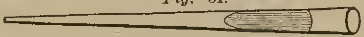
direction resultant of the upward and onward, *i.e.* in a direction in the same angle with, but on the other side of, a line perpendicular to the slab as that in which it descended. Without insisting upon the opinion that these effects may be the result of other causes than repulsion as an independent property of matter, we proceed to consider some phenomena which are adduced as proofs of an original repulsion; some of which are as probably the effect of other causes; and others manifestly depend upon other general properties of matter. A glass ball or watch glass being placed with its convex surface upon a plane surface of glass, they cannot be brought into absolute contact even by a pressure of 1,000 lbs. to the square inch; but this, instead of being an evidence of repulsion, being a general property of matter, may as likely result from the superior energy of cohesion in the different bodies. The same is, doubtless, the cause of the impossibility of reuniting broken glass, stone, or porcelain, by simply pressing the parts together in their former relative positions as far as possible, which has been adduced as a proof of repulsion. A body moving against a spring, or a quantity of confined air, is retarded, not by repulsion as a primary quality of the spring or air, but by their elasticities. In experiments in capillarity if liquids not capable of adhering to the solid be used, *e.g.* mercury and glass, the surface is depressed, being, it is said, repelled; but this may be owing to the particles of the liquid having a greater attraction for each other than for the solid, together with the contractible force at the surface being exerted under circumstances calculated to render the surface convex. If the glass be tubular, and all air be expelled from it by boiling the mercury in it, the depression will be greater as the size of the tube is less. If the tube be coni-

Fig. 30.



cal and contain a limited quantity of mercury, both extremities of the liquid will be convex, and the tension of that towards the narrower part of the tube being greater than the other, the mass will move towards the larger part of the tube. Such facts have been considered as proving the existence of repulsion as a primary general property of matter;

Fig. 31.



and the advocates of this opinion assert that glass always repels and never attracts mercury, but very minute particles of mercury do adhere slightly to glass; and that glass attracts mercury appears from an observation made in 1672, and repeatedly confirmed, viz. a barometer tube being thoroughly cleansed by alcohol, filled with mercury, and freed of air, upon carefully turning it and immersing its open end in mercury, the whole column will remain suspended, and require several slight taps to bring it to the existing barometrical level. If two balls, one of which can be moistened by water, and the other cannot, e.g. balls of cork and wax, be brought within capillary distance upon a surface of water, the former will elevate water upon its side, the more distant surface of the elevated water being inclined, and the other ball not adhering, an apparent repulsion takes place.

Fig. 32.

POLARITY.

58. Polarity is that property of matter which causes bodies to assume certain positions, and in most cases to exhibit peculiar properties at certain points called "poles." It is thought that in all cases of polarization opposite kinds of polarity are excited; and the visible phenomena result from this double excitement. Loadstone attracts iron at certain points on its surface called poles. These poles

rubbed on steel impart to it the same property, which is greater near the extremities. If this steel be then suspended so as to be free to move, the extremities will point one uniformly nearly north, and the other equally south: these extremities are therefore called "poles;" which term has hence come to be more extensively used. The whole piece of steel is called a "magnet." Similar poles repel and dissimilar attract each other. If a magnet be broken into several pieces, each will be found to be a magnet. The whole magnet is therefore considered as made up of a number of smaller magnets: the middle of the mass of steel does not attract iron because the opposite kind of poles there to some extent neutralize each other.

59. Bodies electrically excited exhibit analogous phenomena; similarly electrified bodies repelling, and dissimilarly electrified attracting each other. Bodies near to, but not in contact with, an electrified body have their parts nearest it brought to an opposite state of electricity, and the further sides to the same state with the electrified one. In the voltaic pile there appears to be a current of action from the metal most acted on to the other, through the intervening material, and by the conductor back to the former. The two extremities of the pile, or of conductors connected with them, are called its "poles," as it is at them that the action becomes apparent.

60. Perfectly formed crystals exhibit a regularity of form, which is not confined to their exterior; but is found to pervade their whole structure; showing that in the formation of the crystals their particles did not approach each other indiscriminately, but were influenced by a force which induced them to take certain positions in preference to others. A quantity of water may hold finely divided solid matter in a state of suspension and matter in solution, this having entirely lost its solid form: if the vessel be kept perfectly still the former will in time be deposited uniformly

on the whole bottom, perhaps in layers if the particles differ in weight; the latter will also be deposited, but more slowly and differently from the former; it will be accumulated regularly about certain points which exert a controlling influence over the particles, causing them to unite by certain faces in preference to others, upon lines bearing certain relations to these points, the result being the formation of regular geometrical figures, called crystals. The points referred to have been compared to the poles of a magnet; and there are strong reasons for supposing that the whole action is connected with the magnetism of the earth.

61. Chemical affinity is considered by many as depending on a kind of polarity of the molecules, as may be illustrated by an example. Zinc and hydrochloric acid are considered as polarizable, but their polarities are manifested only when they are brought in contact. One atom of hydrochloric acid may be considered as a polarizable molecule, and two atoms of zinc as constituting another: when a quantity of each is brought in contact they may be considered as constituting two trains of molecules, one of acid and the other of zinc. Of the acid train the molecule in contact with the zinc has the polarity, which is called "chlorous," excited in it, and, the particles being free to move, the chlorine takes position next the zinc, while the hydrogen having become polarized with the zincous polarity excites the contrary polarity in the chlorine of the next molecule, and so on: at the same time one of the atoms of the zinc molecule next the acid acquiring the zincous polarity, the other becomes chlorous, and renders one in the next molecule zincous, the other becoming chlorous acts in the same manner upon a third molecule, etc. These polarities having acquired a certain degree of force, the atom of chlorine is disengaged from that of hydrogen and unites with the opposite one of zinc, forming chloride of zinc, which passes from the field of action: the hydrogen also passing

off as a gas, fresh molecules of acid and metal act in the same way.

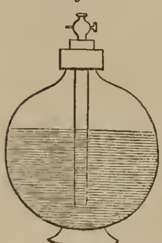
ELASTICITY.

62. Elasticity is that property of matter by which it resumes its primitive condition upon the removal of any extraneous force, which may have changed its form or dimensions. All bodies are elastic, that is to say, they can, without being disaggregated, suffer a change of form and volume and resume exactly their primitive condition upon being released, provided their molecules do not suffer too great derangement of aggregation. Bodies vary greatly in elasticity as compared with each other: thus balls of ivory are more elastic than balls of lead, for they recover from greater compression: plates of steel than plates of glass, for they can be bent much further and recover their position: threads of silk than of silver or copper, for they can be twisted much more: cords of a violin than iron wire, for they can be drawn out much more and return to their primitive length. A sheet of paper or of lead is not destitute of elasticity; for either can be bent slightly without breaking or ceasing to resume its position; but if they be bent too far their elasticities are forced, and they make no effort to return. This property varying greatly in extent and perfection in different bodies, they are divided into elastic and inelastic, or into perfectly and imperfectly elastic. A perfectly elastic body is one that resumes its original dimensions immediately upon the removal of, and with an energy equal to that of, the disturbing force: within certain limits perhaps all bodies may be said to be perfectly elastic. India rubber is extensively but imperfectly elastic, for if long heated or often or much stretched it becomes permanently elongated. Glass is perfectly elastic but only

to a small extent, for it retains no permanent bend; and will not bend far without breaking unless in very thin pieces or fine threads. The exercise of elasticity is always consequent to a disturbance of molecular equilibrium. Elasticity may be considered as occurring in gases, liquids and solids, and, in reference to the occasion of its exercise, as of compression, traction, bending and torsion.

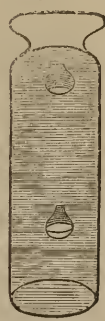
63. *Elasticity of Gases.* The only elasticity exhibited by gases is that of compression; their volume, at any given temperature, always depending on the pressure to which they are subjected. Airs are perfectly elastic: thus air entirely filling a vessel being compressed into half its bulk will, immediately upon removing the pressure, reoccupy the whole vessel. The extent of their elasticity is much greater than that of liquids or solids. This elasticity may be illustrated by a variety of experiments. Baked apples or shrivelled fruit, *e.g.* raisins whose skins are entire being under the receiver of an air pump, upon exhausting it, the air in their pulps will expand and impart an appearance of plumpness to them. Hot water half filling a vessel placed in the same situation will, upon exhausting the receiver, appear to boil rapidly, owing, in part, to the escape of air. A quantity of air being forced by a condensing syringe into a closed vessel through a tube terminating under water which partially fills the vessel, if a stop-cock attached to the upper part of the tube be closed and a jet put into the place of the syringe, upon opening the stop-cock the elasticity of the confined air will drive out the water to a distance proportioned to the compression of the air. A glass globe being blown to such thinness as to be but a little heavier than water, and having a small orifice at what is its lower part when swimming in water, being filled with water except a small space

Fig. 33.



occupied by air, being placed in water will sink: the whole being now placed under the receiver of an air-pump, upon exhausting this the pressure being removed from the surface of the water is likewise removed from the air in the globe, which, owing to its elasticity, expands and drives the water out of the globe, which with its contents become lighter than water and rise. This experiment may be so modified as to dispense with the use of the air-pump: the quantity of air in the globe being accurately adjusted, so that it will swim, and the outer vessel being but partially filled with water, its orifice is closed with a piece of India rubber whose external surface is convex: by pressing upon this with the palm of the hand the air within the globe is compressed and water entering, the globe sinks; upon removing the hand the air expands and the globe rises. If the atmospheric pressure be removed from a glass phial, with flattened sides, made very thin, and having its orifice tightly closed, the elasticity of the air within will rupture the sides, sometimes breaking the whole vessel into small fragments.

Fig. 34.



The utility of bellows depends upon the elasticity of air. The common bellows being constructed of two pieces of board connected by a pliable material between; the lower board has a valve which opens when the boards are separated, and air is then admitted, but cannot return that way, as the valve closes on bringing the boards together, the air is then driven through the tube. The double bellows used by blacksmiths and others differs from that just described in being separated into two apartments by a middle board furnished with a valve opening upward; while the partition is fixed, the lower board is elevated by a cord and descends by its own weight; as it de-

scends air enters through its valve, and being compressed by the rise of the board, passes to the upper apartment, elevating the top; this top, in its descent, which may be aided by additional weights, forces out the air through the pipe.

If a barometer tube be partly filled with mercury, leaving an inch or two containing air, a finger being placed on the open end so as to confine the contents, upon inverting it into a vessel of sufficient depth filled with mercury: upon removing the finger and pressing the tube down till the mercury stands at the same level within and without, the air within will be under the pressure of one atmosphere: if it be now raised till the air be doubled in bulk, the mercury will be found to be raised half as high as in the barometer. This column resists half the pressure of the atmosphere, and the confined air is to that extent relieved. The tube being raised till the volume of air is tripled, the mercury will attain to but two-thirds the barometer height, and will sustain that proportion of the atmospheric pressure, while the air sustains but one-third.

Vapors form immediately in vacuo, but more slowly under ordinary circumstances, the formation being then resisted by the elastic force of the air, to which resistance is added that of every successive portion of vapor formed. The elasticity of different vapors is different, and may be measured by the degree to which the mercury in a barometer is depressed by the introduction of a few drops of the liquid, this depression being due to the formation of vapor. The greater the volatility of a liquid, the greater is the elasticity of its vapor. Thus the elasticities of the vapors of water alcohol, and ether, are as 1, 1·9 and 20. The elasticity of all vapors is increased with the temperature, as may be shown by placing a heated ring around the part of a barometer into which a liquid has been introduced: in every case, at the boiling point of the liquid, it equals the pressure of the

atmosphere. Hence, whenever it is required to determine the volume of a gas, it should be done at a given temperature, or calculation should be made from that at which the measure is taken. Experiments of the kind that have been here considered have led to the general conclusion known under the name of Mariotte's law, viz. The volumes of elastic fluids are in the inverse ratio of the weights by which they are compressed. This law has been experimentally found applicable to air without variation, to the extent of 27 atmospheres. A justifiable inference from this is, that the densities of gases are proportional to the pressures to which they are subjected. Thus, being under the pressure of 700 atmospheres, air would be as dense as water. Many gases formerly considered permanently elastic, have been reduced to the liquid state; and it has been thought that all could be brought to the same condition if sufficient pressure and reduction of temperature could be commanded. Those which have not been condensed have been found to be subject to the above law to the extent of a hundred atmospheres' pressure. In those which are capable of assuming the liquid form, a deviation from the law is very marked as they approach the point of liquefaction; and in some it has been observed almost from the beginning of the compression. It has also been conjectured that the law would fail in cases of extreme rarefaction.

Fig. 35.

64. *Elasticity of Liquids.*—Liquids are perfectly elastic, but to only a small extent. Like gases, they exhibit only the elasticity of compression. To compression they offer far greater resistance than gases do. The experiments proving their compressibility likewise manifest their elasticity, for upon removing the compressing force they recover their original bulk. It is also exhibited by their being

scattered in drops when falling from a height upon a smooth surface, solid or liquid.

65. *Elasticity of Solids.*—Several examples have already been given of elasticity in solids; in this class of bodies, however, it is far less perfect than in liquids or gases. Elasticity of solids may be considered in reference to the manner in which their molecular equilibrium is disturbed, as already indicated, viz. the elasticities of compression, traction, bending, and torsion.

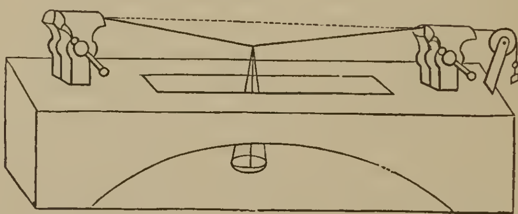
I. *Elasticity of Compression.*—The experiment of the ivory ball falling upon a marble table, adduced as an evidence of repulsion, may perhaps be more accurately considered as an example of elasticity of compression, the rebounding of the ball being probably only the consequence of the elasticities of the ball and table. The ball is thought to be some moments in recovering permanently its globular figure, being ellipsoidal, with its horizontal and vertical diameters alternately longer. The cork of a bottle sunk in the sea having recovered its position after being compressed sufficiently to allow the salt water to flow into the bottle, is evidence of its elasticity; but its not recovering its original bulk when the pressure has exceeded a certain limit, shows that its molecules have been brought into a different range of elasticity. Malleability is connected with, and to some extent opposed to elasticity of compression. Brittle metals being hammered, their cohesion is so far overcome that they fly to pieces; those which are malleable, however, are not so separated, but by that means, or by being passed between rollers, their molecules are brought into different ranges of elasticity; their hardness and brittleness are sometimes increased, and if to a great extent they tear, when they are said to be hammer-hardened. Steel is tempered by plunging it when heated into cold water, by which its surface is cooled and hardened, in consequence of which the parts within are in a constrained

state, and have a strong tendency to change their positions, which renders the mass quite brittle. Prince Rupert's drops are made by allowing drops of melted glass to fall into cold water; they have somewhat the shape of a tear, with a prolongation called the tail; the outer crust being suddenly contracted, compresses the parts within, whose elasticity forces the whole mass asunder with noise on the surface being scratched or the tail being broken. The utility of elliptical springs of carriages, and of similar contrivances, depends on the elasticity of compression.

66. II. *Elasticity of Traction.*—As would naturally be expected, it is found by experiment that during extension of wires, rods, or bars, the diameter perpendicular to the axis is diminished as the length is increased, but not to the same extent. If they have not been stretched beyond certain limits they resume their original size when the stretching force is removed; if, however, those limits be exceeded, they are found to be permanently increased in length, and diminished in thickness, their molecules taking a different range of elasticity. If the force applied be very great they will be broken, either abruptly through their whole thickness or by slowly becoming thinner and thinner. That very flexible wires are perfectly elastic within certain limits, and that they are elongated in proportion to the force applied, may be shown by two vises placed horizontally, in one of which is securely fastened one end of the wire, which is extended by a weight through the other vise till it is rendered straight; that vise is now closed upon it. The length of the wire between the two vices, and the height of its middle from the support, being now accurately determined, a scale is suspended from that point, and weights, the force to be applied, are placed in the scale, and the distance which the same point of the wire descends is carefully ascertained. (Fig. 36.) From these data, the extension which the wire has suffered is calculated by rules of trigonometry. The

elasticity of large rods or bars can be determined in the same way, by placing their ends on firm supports and applying weights exactly upon the middle; or if they be strong and firm a different method can be adopted. They are placed vertically, being fixed at their upper end and the weight applied at the lower. The elongations are

Fig. 36.



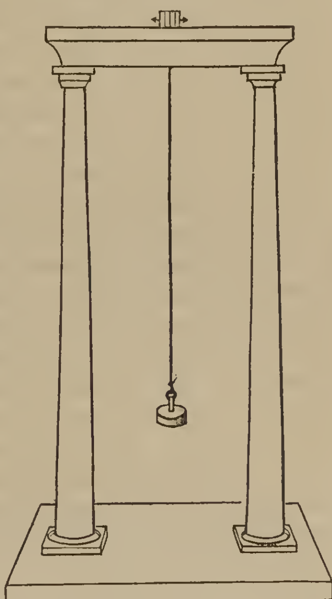
found in either way to be proportionate to the force of traction; the extent, however, depends upon the nature of the material; and, upon removing the force, contraction occurs equal to the elongation, unless the limit of elasticity be surpassed. Elasticity of stretching has the same relation to ductility that elasticity of compression has to malleability. The tendency of liquids to force asunder vessels containing them is capable of being understood by viewing each section as a flexible ring, all of whose points are pressed from within outwards: the force of pressure becoming tangental tends to stretch, and then to break the ring, as though it were straight and the force acted in the direction of its length.

67. III. *Elasticity of Bending.*—Bodies capable of being bent exhibit more or less elasticity: in some it is manifested as a great force. In bending, the particles on the convex side of the curve are in a state of extension, while those on the concave side are in one of compression; and both co-operate to resist the bending, and to overcome it

when the force is removed. The elasticity of wood is well illustrated in the cross-bow. It is great, but not perfect; for if long continued the bend becomes permanent. Mica affords a good example of a mineral possessed of this kind of elasticity. In glass it is very slight, for much bending breaks it.

68. IV. *Elasticity of Torsion* is that force by which a wire or thread which has been twisted tends to return to its natural position. It may be exhibited by means of a vertical thread, secured by its upper end, and supporting a ring firmly attached to a large cylinder of lead or casting, whose axis corresponds to the vertical diameter of the ring. The application of weights to the cylinder will cause the untwisting of the thread, which after repeated oscillations comes to rest. (Fig. 37.) With such an instrument the following generalizations have been established: 1st. A thread charged with different weights is generally arrested at different positions of stability. The variation can extend to a semi-circumference, or even to circumference. The same is true of a collection of threads. A magnetic needle being suspended by a silk ribbon the application of greater or less weight would affect its diurnal variations. 2d. The oscillations are isochronous, whatever may be their amplitudes, unless these

Fig. 37.



surpass certain limits, depending on the nature and length of the thread, which limit is often a semi-circumference, or even a circumference. This is established by arranging, as above, a thread, and placing on the cylinder a weight sufficient to straighten, but not to elongate the thread, and when the equilibrium is well established, turning the cylinder 50, 100, or 180 degrees without changing the axis, and letting it oscillate. The oscillations are counted by means of a mark or index attached to the cylinder; and the time is measured by a good second-hand watch. A corollary from this is that the force of tension is proportioned to the angle of tension. 3d. The times of the oscillations are to each other as the square roots of the weights which stretch the threads. The truth of this law can be exactly established only where the threads have sufficient flexibility to be straightened by a feeble weight, and yet too much tenacity to be lengthened by a considerable one. This law holds good only while the force of torsion of a thread remains the same under the different weights which stretch it. 4. The times of oscillation are as the square roots of the lengths of the threads. The time of oscillation increasing with the length of the thread, the force of torsion evidently must diminish. 5th. The times of oscillation are inversely as the squares of the diameters of the threads. The forces of torsion are as the fourth powers of the diameters of the threads. The knowledge of elasticity of torsion has been applied to determine, by means of the torsion balance, certain fundamental laws of electricity and magnetism, and by means of a small silver thread the density and total weight of the earth.

CONSTITUTION OF MATTER.

69. In reference to the constitution of matter, very differ-

ent hypotheses have been advanced, some of which may be here noticed.

I. *The Atomic.*—According to this hypothesis, matter is formed of extremely minute particles called atoms, differing in form and nature, and having rectilinear motion, which causes some that are homogeneous to unite, while the others continue diffused through space. An extensively received modification of this hypothesis views the ultimate atoms as points beyond our research, which, under the influence of the so-called imponderable forces, unite to form molecules, which again unite to form particles, the smallest portions into which matter can be mechanically divided.

II. *The Dynamic.*—This hypothesis views matter as originated by two antagonistic principles, attraction and repulsion, and refers all that may be affirmed of matter to motion. Most modern physicists, uniting these hypotheses, consider the Deity as the origin or first cause of atoms, and innate attractive and repulsive forces as a condition necessary to their uniting into bodies. By some repulsion is considered, with appearance of great probability, as dependent upon heat, an atmosphere of which is supposed to permeate all space and all masses of matter, surrounding all the atoms, thus preventing their ever coming into absolute contact.

III. *Which may be called the Potential.*—According to this view, the atoms, instead of being dead particles, are extensions of forces from centres or mathematical points throughout all space, being tied together, however remote they may be, by lines of mutual force, all gravitating, bearing electrical relations to each other, being elastic, expansible on change of temperature, suffering repulsion on becoming gaseous, being bipolar or multipolar, and interpenetrating and losing their proper characteristics on chemical combination just as masses do, being present chemically and mechanically within certain small limits, and everywhere beyond those limits gravitantly and electrically, thus con-

stituting the ether, by whose undulations light and heat are propagated, with the lines in which they are exerted, occupying all space to the exclusion of everything else. This hypothesis entirely denies the materiality of matter.

FINIS.

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